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THEORY OF THE SLIDING FRICTION OF ROTATION.

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Sliding friction in systems of mechanism gives rise to losses of energy and to increase of resistance which are usually very considerable, and which are often the only sources of "lost work," and of the reduction of efficiency below its maximum value—unity. In any well-proportioned and properly managed machine or train of mechanism, the wastes of energy are due solely to friction; in badly-proportioned mechanism, subject to overstrain or shock, causing deformation of parts, energy is lost equal in amount to the work expended in producing permanent distortion. But as the engineer generally only considers cases of correct construction in determining the magnitude of such waste, it may be asserted, as a general and fundamental principle, that, in all good engineering, the sole cause of waste of mechanical energy is friction. These facts and this principle sufficiently indicate the importance to the engineer of a careful study of the magnitude and of the method of such losses.

The writer has elsewhere* given the results of experimental determinations of the values of the coefficients of sliding friction, and has shown that the lost work in mechanism varies very greatly in amount; that it is, under favorable circumstances, vastly less than has been generally supposed; and that it is influenced, where lubrication is employed, by every change of velocity of rubbing, of temperature, and of intensity of pressure, as well as by the character of the lubricant.

In machinery and mill-work, and in mechanism generally, it is usually found that the wastes of energy caused by sliding friction are principally due to friction of rotation; *i. e.*, to the friction of shafting, of journals, and of pivots in their bearings. This form of friction, and this method of waste, are the subjects of the paper here presented. The friction of straight sliding pieces has been frequently studied and is well understood; that of rotation has been less fully investigated, although considered at some length in a few treatises. The importance of the subject is such, however, as will justify the most extended examination.

The Friction of Journals causes a waste of the energy traversing a machine, which is dependent in amount upon the velocity of rubbing, the magnitude of the load, the method of distribution of the resulting pressure, and of variation of its intensity, the size of the journal, the nature of the lubricant and its physical condition, especially as determined by its

* *Friction and Lubrication*, Railroad Gazette Publishing Company, New York, 1878. *Materials of Engineering*, Part I., 2d Edition, J. Wiley & Sons, New York, 1884.

temperature, and on the value of the coefficient of friction as determined by all these modifying conditions.

A journal in good order, well-fitted, and smoothed down by prolonged working, should never show evidences of measurable wear. Such journals have sometimes been known, by the writer, to show no appreciable alteration of form and fit after years of constant work.

The First Case of permanent fit of journal is that in which the journal is exactly fitted to its bearing when new, and so perfectly adjusted that no sensible wear takes place. In this case, the pressure brought upon the rubbing surface by the load is distributed by a certain method of yielding of the loaded metal, and according to a simple and definite law, the investigation of which is one of the principal objects of this paper. Under this law, an adjustment takes place which, if the bearing surfaces are sufficiently large, of good material, and well lubricated, is permanent.

The Second Case is that in which wear occurs, and until all parts of the journal and bearing in contact wear until a "fit" is thus attained, such that every part is compelled to carry equal pressure, and until wear ceases to be observable.

The Third Case to be considered is that in which the journal is loose and the bearing surface, or surface of actual contact, is assumed to be a straight band of inconsiderable width.

These are the three typical cases for cylindrical journals, and these cases only are to be here studied. Actually, in practice, probably, neither case is often met with; the real condition of the journal is usually intermediate between one or the other pair of these type-examples.

It is evident, from what has been just stated, that the friction of journals, other things being equal, depends greatly for its amount upon the method of distribution of pressure, and is not necessarily, and probably may not be often, measured exactly by the product of the load on the journal by the coefficient of friction. It may be sometimes, and in fact often is, very much greater. It thus becomes an important problem to determine the manner in which variation of intensity of pressure affects the total resistance due to friction, and the method of that variation as produced by the different modes of fitting journals.

THE WORK DONE AND HEAT DEVELOPED, by the friction of any journal, is measured by the product of the total normal pressure on its rubbing surfaces into the mean coefficient of friction, and into the space traversed by the surface of the journal, relatively to the surface of the bearing, in the given time.

If p represent the mean intensity of pressure, l the length of journal, θ the angle over which the pressure distributed, r_1 the radius of the journal, f the mean coefficient of friction,* and n the number of revolutions made in the given time, the work of friction will evidently be

$$\begin{aligned} U &= p.l.r_1\ \theta.\ f.\ 2\,\pi\,r_1\,n \\ &= 2\,\pi\,r_1^2\,f\,p\,l\,n\,\theta \quad . \quad . \quad . \quad (1) \end{aligned}$$

When $\theta = \pi$, as in a journal receiving no pressure from its cap,

$$U = 2\,\pi^2\,r_1^2\,f\,p\,l\,n;$$

and when $\theta = 2\,\pi$, as when the cap is screwed down hard,

$$U = 4\,\pi^2\,r_1^2\,f\,p\,l\,n.$$

When the load is fixed, the intensity of pressure varies inversely as the area of the journal, and $p\,l\,r_1\,\theta$, becomes constant. Hence in such cases, the resistance of friction, $f\,p\,l\,r_1\,\theta$, is constant, and the work of friction and energy wasted becomes proportional to the diameter of the journal; while both quantities are independent of the length, except so far as it affects the coefficient of friction. Journals are therefore properly proportioned by making their diameter such as is dictated by considerations of strength and safety against "springing," and determining their length by reference to the loss of work by friction and the liability to heating.

The minimum limit, as to length, is set by this last consideration. As has been fully shown by the writer, the coefficient of friction increases with increase of bearing area and consequent decrease in intensity of pressure; the conclusion therefore follows that bearings should be as short as is consistent with security against heating. This conclusion is the more

* With good lubrication, it may be assumed that, in heavy machinery and under pressures not far from 100 pounds per square inch (7 kgs. per sq cm.), the value of f may be reduced below one per cent., varying approximately inversely as the square root of the intensity of pressure.

important from the fact that a long journal is liable to spring, and thus to concentrate pressure at the end, and to cause heating in that way. With every diameter of shaft, therefore, there is a limit beyond which no increase of length of journal will prevent heating. With a given shaft, heating under a given load, no increase of diameter will reduce liability to heat—if the shaft does not spring—and increasing its length may afford advantage only up to a limit.

The Heat Due to Friction, H, is proportional to the work done on the journal, and is measured in thermal units by the quotient of that work U, by the mechanical equivalent of heat J, *i. e.*,

$$H = \frac{U}{J} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This heat is carried away by conduction to adjacent masses, and by radiation. If it is carried away as rapidly as it is produced, the journal remains cool; if not thus carried off, the journal heats up until the rate of dispersion is equal to that of production, or until it becomes necessary either to apply cooling agents or to stop the machine.

The Temperature Attained by a journal when thus heating is limited by the facilities for conduction and radiation of heat from it. The maximum *safe* temperature is that beyond which liability to rapid and dangerous heating is incurred, and is always below the temperature of decomposition or vaporization of the lubricant. A warm journal will often work better than a cold one; a hot bearing is always a source of danger. A journal so proportioned as to run warm with good lubrication is to be watched with the utmost care. As already seen, since the tendency to heat increases directly as the intensity of pressure, and as the amount of work done, and inversely as the area across which the heat can be transmitted, the diameter of the journal, if it be sufficiently strong and stiff, does not affect this phenomenon.

Case 1.—The Perfectly Fitted Journal is the most interesting of the three cases here to be considered. When a journal is exactly fitted to its bearing,* as is usually the fact, without pressure, the action of the load will cause a minute change of form, which, although quite imperceptible, will produce a variation of intensity of pressure between the rubbing surfaces, from a maximum on the portion normal to the line of direction of the resultant load, to zero on the surfaces parallel to that line, and according to a simple and easily determined law.

This Method of Distribution of Pressure, which was, as he believes, originally investigated by the writer, is determined in the following manner:

The maximum intensity of pressure under which any journal of good form and correct proportions may be worked, is from 500 pounds to the square inch, with iron journals, to about 1,000 pounds with steel (35 to 70 kgs. per sq. cm.); the elastic limit of the bearing metal is always far above these figures, and that of the metal of the journal usually very much higher still. The compression of the metal, under working pressure, will be proportional to the intensity of the pressure at each point, and this principle will determine the law of distribution of pressure. The intensity of the pressure will be everywhere proportional to the elastic displacement of the metal.

Let p represent the intensity of pressure on any element of the surface of the journal having a length l, and a breadth $r_1\, d\theta$, and let N represent the normal pressure on this elementary area $l r_1\, d\theta$; then

$$N = p\, l\, r_1\, d\theta \quad . \quad . \quad . \quad (3)$$

The sum of all the vertical components of these elementary normal pressures, $p = N \cos.\ \theta$, where θ is measured from the vertical, is equal to the load W on the journal; *i. e.*,

$$W = \int p\, l\, r_1 \cos.\ \theta\, d\theta. \quad . \quad (4)$$

But the normal pressure p varies from a maximum, at the bottom of the bearing, to a minimum at the sides, there becoming zero when the bearing is a semi-cylinder. At intermediate points the normal pressure is

$$p = p_1 \cos.\ \theta,$$

in which quantity p_1 is a constant, the value of which is to be determined. The value of p being obtained, and introduced into the formula,

* The custom now common of grinding journals to size, and sometimes of scraping the bearing, makes this an increasingly frequent case.

$$W = p_1 l r_1 \int \cos.^2 \theta \, d\theta. \quad . \quad (5)$$

which is to be integrated between the limits

$$\theta = +\frac{\pi}{2}, \; \theta = -\frac{\pi}{2},$$

to obtain W in terms of p_1, when the journal bears upon a semi-cylindrical surface, or between the positive and negative values of θ for any other method of bearing. From the relation thus obtained the value of p_1 is deduced. It will be seen that p_1 is the measure of the maximum intensity of pressure between the rubbing surfaces, occuring when $\theta = 0$, *i. e.*, at the bottom line of the bearing.

To Determine the Maximum Pressure p' on the journal, let A Ć B, Fig. 1, repre-

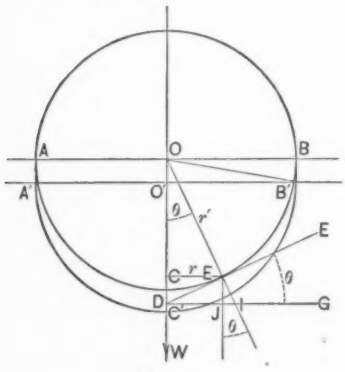

Fig. 1.

sent the trace of the bearing surface upon the vertical plane, the journal being perfectly fitted and unloaded. When the load comes upon it the journal will sink a minute distance, O O′, C C′, A A′, B B′, and will rest in equilibrium between the elastic resistance to compression, thus brought into play in the metal, and the weight sustained by the bearing, the surfaces of contact taking the new position A′ C′ B′, of which every point now lies directly under its original position, and at a distance from it equal, at every point, to O O′. The compression of the metal in the direction of the normal pressure p, will be at each point, as E, equal to E I. The product of this vertical displacement, E J, into cos. θ; and the intensity of the pressure, the elastic limit of the metal not being exceeded, will be proportional to this compression, varying from 0 at B′ to a maximum p' at C′. At any intermediate point, the compression is, for a small total depression of the shaft $\overline{O\,O'}$ cos. θ, and the intensity of the pressure, consequently, p' cos. θ.

Since the load, W, is sustained by the sum of the vertical component of these normal pressures, each of which is of the intensity,

$$w = p \cos. \theta = p_1 \cos.^2 \theta,$$

$$W = \Sigma w = p_1 l r_1 \int_{-\theta'}^{+\theta'} \cos.^2 \theta \, d\theta,$$

$$= p_1 l r_1 \left(\tfrac{1}{2}\theta' + \tfrac{1}{4} \sin. 2\theta\right)_{-\theta'}^{+\theta'}$$

as before, and

$$p_1 = \frac{W}{l r_1} \div \left(\tfrac{1}{2}\theta + \tfrac{1}{4} \sin 2\theta\right)_{-\theta'}^{+\theta'} \quad . \quad . \quad (6)$$

When $\theta' = \frac{\pi}{2}$,

$$p_1 = \frac{W}{1.57\, l r_1} = \frac{0.64\, W}{l r_1};$$

and the pressure at any point, E, of the journal, has the intensity,

$$p = p_1 \cos. \theta = \frac{0.64\, W \cos. \theta}{l r_1} \quad . \quad . \quad (7)$$

When $\theta' = \frac{\pi}{3}$,

$$p_2 = \frac{W}{1.48\, l r_1}; \; p = \tfrac{2}{3} \frac{W \cos. \theta}{l r_1}, \text{ nearly}; \quad (8)$$

and the maximum pressure is nearly equal to four-thirds the load on the journal divided by its projected area on the horizontal plane, and is very nearly the same as in the previous case, although one-third the bearing surface has been removed. This is often done by engineers in charge of heavy machinery, to prevent risk of "gripping" or "binding," should the bearing heat.

It is evident that the same method applies to the case of the spherical journal.

The Extent of Compression is determined by the magnitude of the modulus of elasticity of the metal compressed, thus, for a pressure of 1,000 pounds per square inch (70 kgs. per square cm.) on a bronze bearing, the maximum compression would be but $\frac{1}{12000}$ the thickness of the "brass."

The Force of Friction, at any element, E, is, for the full journal,

$$fp=\frac{0.64\ \mathrm{W}\cos.\theta}{l\,r_1}, \quad . \quad . \quad . \quad . \quad (9)$$

and varies from zero at $\theta=90°$ to a maximum, at $\theta=0$, when

$$fp_1=\frac{0.64\ \mathrm{W}}{l\,r_1}.$$

The Total Pressure on the bearing is

$$\mathrm{P}'=0.64\ \mathrm{W}\int_{\theta=-\frac{\pi}{2}}^{\theta=+\frac{\pi}{2}}\cos.\theta\,d\theta$$

$$=0.64\ \mathrm{W}\left(2\sin.\frac{\pi}{2}\right)$$

$$=1.27\ \mathrm{W}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The Total Force of Friction is

$$f\,\mathrm{P}'=1.27\,f\,\mathrm{W} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

The Moment of Friction is

$$\mathrm{M}=f\,\mathrm{P}'\,r_1=1.27\,f\,\mathrm{W}\,r_1 \quad . \quad . \quad (12)$$

The Work of Friction is

$$\mathrm{U}=\mathrm{M}\,a=1.27\,f\,\mathrm{W}\,a\,t\,r_1$$

$$=2.5\,f\,n\,r_1\,t\,\pi\,\mathrm{W}, \quad . \quad . \quad . \quad (13)$$

where a is the angular velocity of the shaft, t the time taken, and n the revolutions made in the unit of time.

The Power lost in Friction is

$$\mathrm{U}\div 550\,t=2.5\,f\,n\,r_1\,\pi\,\mathrm{W}\div 550, \quad (14)$$

when the units are British and the time is measured in seconds.

As will be seen later, the resistance, the work done, and the power wasted, are 1.3 times as great as in a journal loosely fitted, in which the rubbing surfaces are in contact only along a narrow band parallel to the axis of the journal. The case above considered assumes a fit originally and no subsequent wear. In such case, the journal must be of such size that the maximum pressure, p_1, may be below that at which the unguent is liable to be forced out, or heating to occur.

Case 2.—Uniform Pressure on the Rubbing Surfaces may be observed in cases of journals so small as to wear slowly under their loads, or, perhaps, when heating, as is often the case, causes the "brass" to grasp the journal by springing the sides inward. Both are familiar cases to every mechanical engineer who has had much experience, especially if accustomed to the management of steam machinery.

In well-designed machinery, a bearing is usually composed of a softer metal than the journal which it supports; it therefore takes the wear, and if the extent of rubbing surface is small the journal is merely "smoothed up," while the bearing wears down. If the surface is too small, the bearing may be abraded and "cut," and both it and the journal rapidly injured. If, however, the surface under pressure does not cut, wear takes place slowly, and without excessive waste by friction. Every bearing surface, if not abraded, will, whether fitted or not, wear under heavy pressure, but with decreasing rapidity, until all parts sustain a certain intensity of pressure, when the rate of wear becomes a minimum, under a pressure which is a minimum for that bearing under the existing conditions as to lubrication. In some cases, the whole bearing surface may not be brought into play, the uniform pressure, so established by wear over a part of it, being sufficient to carry the load without further wear. These two cases are probably the most usual in all cases of heavily loaded, or carelessly fitted, journals, as the preceding case represents the usual case of well-fitted, lightly, or fairly loaded bearings. in every case, there is a certain pressure-limit, above which wearing will take place and below which it becomes inappreciable; the bearing will therefore wear down until the pressure due the load is so distributed that this pressure-limit is everywhere reached over a certain limited area, and wear ceases, or until all parts of the bearing are brought to a state of minimum wear under a uniformly distributed pressure.

In the case here studied, the pressure is of uniform intensity, p_1; that on any elementary strip of bearing, of length l and breadth $r_1\,d\theta$, is $p_1\,l\,r_1\,d\theta$; its vertical component is $p_1\,l\,r_1\cos.\,\theta\,d\theta$, and the total load is, for a semi-cylindrical journal,

$$\mathrm{W}=p_1\,l\,r_1\int_{\theta=-\frac{\pi}{2}}^{\theta=+\frac{\pi}{2}}\cos.\,\theta\,d\theta$$

$$=2\,p_1\,l\,r_1; \quad . \quad . \quad . \quad . \quad (15)$$

and the intensity of the uniform pressure attained is

$$p_1 = \frac{W}{2 l r_1} \quad . \quad . \quad . \quad . \quad (16)$$

The Total Pressure on the journal surface is

$$P' = p_1 l \pi r_1$$
$$= \tfrac{1}{2} \pi W = 1.57 W \quad . \quad . \quad . \quad (17)$$

or 0.57 greater than the load.

The Total Force of Friction is

$$f P = 1.57 f W \quad . \quad . \quad . \quad . \quad (18)$$

The Moment of Friction is

$$M = f P' r_1 = 1.57 f r_1 W \quad . \quad (19)$$

The Work of Friction is

$$U = M a = 1.57 a f t r_1 W$$
$$= \pi_2 f n t r_1 W,$$
$$= 10 f n t r_1 W, \text{ nearly.} \quad (20)$$

or 1.57 that on a flat surface, or on a loosely fitting journal.

Were the angle of contact reduced, making the angle $\theta' = 30°$, the friction becomes but 5 per cent. greater than that of an equally loaded flat surface, or of a loose journal. It is thus seen that, where ample area of bearing surface can be secured, it is best given the form of a strip or band lying along the bottom of a long "brass," rather than made to cover the full semi-circumference of a shorter journal.

Case 3.—A Loosely Fitting Journal, A B C, before wear has produced a sensible widening of the line along which contact originally takes place between journal and bearing, when in operation, carries its load at a line parallel to the axis of the journal, and at one side of the line of vertical resultant pressure (Fig. 2). If at the lowest point, B, at the starting, it rolls up the side of the bearing until, at some point, D, the inclination becomes equal to the angle of friction B N D, E D F, when it ceases its upward movement and continually rotates, sliding on the line whose trace is D, as long as the coefficient of friction remains constant, or rising with increasing, and falling with decreasing, friction, continually finding new positions of equilibrium until motion ceases, or the conditions again become constant.

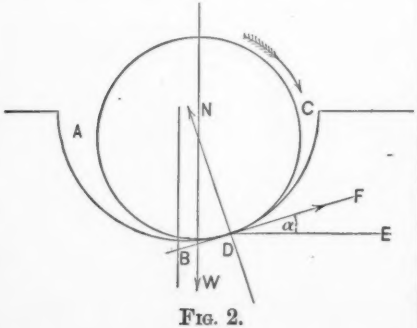

Fig. 2.

At any one instant, there are three forces in equilibrium, the weight W, on the journal, the normal reaction, N, of the bearing, and the resisting force of friction, $F = f N$, which may be represented by the sides of the triangle N B D. Then, since N and F are at right angles

$$W^2 = N^2 + F^2$$
$$= (1 + f^2) N^2 \quad . \quad . \quad . \quad . \quad (21)$$

The Normal Pressure is

$$N = \frac{W}{\sqrt{1+f^2}} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

The Force of Friction is, since $a = \varphi$, the angle of friction,

$$F = \frac{f W}{\sqrt{1+f^2}} = \frac{W \tan. \varphi,}{\sqrt{1+\tan.^2 \varphi}} = W \sin. \varphi \quad (23)$$
$$= f W \text{ nearly.}$$

The Moment of Friction is

$$M = F r_1$$
$$= W r_1 \sin. \varphi$$
$$= \frac{f W r_1}{\sqrt{2+f^2}} \quad . \quad . \quad . \quad . \quad . \quad (24)$$

The Work of Friction, or energy wasted, is

$$U = W a t r_1 \sin. \varphi = \frac{f W a t r_1}{\sqrt{1+f^2}}$$
$$= 2 W \pi n t r_1 \sin. \varphi = \frac{2 W f n t r_1}{\sqrt{1+f^2}}. \quad (25)$$

This case is thus seen to be that producing least waste of work and energy, and hence, in that respect, most desirable; but it is evidently a purely ideal case which can never be obtained in practice. If approached too closely, rapid wear, heating, and all the consequent cost and damages are increased. Case 3d is that of minimum friction, but of maximum wear and heating, as Case 1st that of minimum wear, and Case 2d that of maximum friction. In practice, the best ar-

rangement is usually, so far as the writer can judge from his own experience, that of freeing the sides of the bearing by cutting them away so as to clear the journal entirely to an angle of at least 30° from the horizontal, and even 60° for very long, stiff journals, moderately loaded. This gives a modification of either Case I. or Case II., and, on the whole, minimum friction and wear.

In conclusion, it may be considered proven that:

(1.) A perfectly-fitted cylindrical or spherical bearing of ample area of rubbing surface, will, in the absence of wear, have the pressure distributed in such manner as to make it zero at the sides, and a maximum at the bottom of the bearing, varying at intermediate points as the cosine of the angle included between the given point and the bottom of the journal.

(2.) The friction on such a cylindrical journal, and the lost work, exceed by above one-fourth that of the ideal case of bearing on a line, or that of flat surfaces under the same load.

(3.) A bearing so proportioned as to wear constantly, but without "cutting," will be subjected to uniform pressure throughout the area of rubbing contact.

(4.) The friction on such a bearing is nearly 60 per cent. in excess over that of the ideal case, or on a flat surface similarly loaded; it should always be relieved by freeing the sides from pressure in the manner often practiced by engineers, as above described.

(5.) Any journal, wearing smoothly and symmetrically, and without shake, will in time wear to a fit, such that the pressure upon its surface will be of uniform intensity throughout the whole area brought into bearing, and the rate of wear reduced to a minimum, while the waste by friction becomes a maximum.

(6.) Maximum efficiency of machinery in which journal friction is the main source of waste of work and energy, is secured by giving the journals such diameter that they will neither twist nor spring under their loads, such length that the load may be carried principally on the lower portion of the bearing, and such form that the "brass" shall not bind or grasp the journal, or in any way subject the journal to serious lateral pressures. All lateral pressure due to grasping or binding action decreases efficiency.

The proper size of journal is, as is evident from what has preceded, determined only in part by the consideration of the amount of power and energy lost by its friction. Since to increase or diminish the diameter of a journal increases the speed of rubbing in precisely the same proportion in which it diminishes the intensity of pressure produced by any given load it is evident that the work wasted and the heat produced on the unit of area of bearing surface is approximately the same, whatever the diameter of journal, within moderate limits; for, within such limits the coefficient of friction may be considered as constant. The *diameter* of journal is, therefore, determined by the strength and stiffness demanded, and not by the liability to heat, and is calculated by the rules for strength of materials.

The *length* of a journal is determined by reference to the laws of friction. A convenient method is to fix, by reference to experiment, a quantity of work of friction which may be safely allowed for the proposed journal, reckoned per unit of its area. Thus, the writer has found for the crank pins of marine engines, under intermittent pressure, $60{,}000f$, measured in foot-pounds, to be a good allowance; Rankine found $44{,}800f$ to be a good figure for locomotive practice; $50{,}000f$ is an intermediate figure sometimes taken for general practice. For unintermitted pressure, still smaller values must be taken.

Then the work of friction is nearly per unit of area,

$$\frac{f\,\mathrm{P}\,\mathrm{V}}{l\,d}=60{,}000\,f, \quad . \quad . \quad . \quad (26)$$

and

$$\frac{\mathrm{P}}{l\,d}=p=\frac{60{,}000}{\mathrm{V}} \quad . \quad . \quad . \quad (27)$$

Thus the intensity of pressure is limited by the velocity of rubbing, and the given load, P, on the proposed journal being divided by this pressure, p, the length must be at least

$$l=\frac{\mathrm{P}}{p\,d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

in which expression d is known already by calculations of strength.

ON WATER SUPPLY.

Papers read before the Conference of the Society of Arts on the Water Supply held at the International Health Exhibition in July.

From the "Journal of the Society of Arts."

II.

Sources of Water-Supply.

BY JAMES MANSARGH,

M. Inst. C. E., and M. E., F. G. S., F. M. S.

It used to be a popular belief that if a well were sunk at any place to a sufficient depth into the ground, there would be reached an inexhaustible reservoir of water, a store that had been filled in some mysterious manner at the creation of the world, and would suffice for the use of man for all time.

It is now well known that all supplies of water, whether found upon the surface or below it, in underground depths, are derived from the rain which falls upon the earth, and that it depends upon the geological character of the surface receiving the rain whether it shall run off in the form of streams and rivers, or soak in and be apparently lost.

Rain is produced from the evaporation of invisible aqueous vapor, principally from the ocean, by means of solar heat, its condensation, primarily into the shape of clouds, and subsequently into the form of drops, which fall to the ground.

The sea is thus a storage reservoir of boundless capacity, and the sun is the great prime mover which pumps the water up from this reservoir, distributes it over the land, and lifts it to the hills, where it may be impounded in natural or artificial lakes, and thence delivered by gravitation to the claims below.

After being discharged on the earth in the shape of rain or snow, a part of the water is re-evaporated, but the greater part begins at once to travel downwards, either over the surface, in the form of rills and streams, and so on to the ocean, whence it came, or through the surface, if this is permeable, into fissured or porous rocks below.

A portion of this latter water passing into the ground at high levels, has several courses open to it. It may appear in the shape of springs at lower levels, or rise in the beds of rivers, or run out through fissures on to the sea beach, or sink below sea level, whence it will be recoverable only by artificial means.

Nature has in this way provided water from one great source in ample quantity for the use of man, but works of varying character, under differing local circumstances, must be constructed to store and utilize it.

Altitude and the geological structure of a district are the two principal factors which determine what the source of water supply must be in such a district. The two great classes into which sources may be divided are (*a*) above-ground and (*b*) under-ground sources.

The former (*a*) has several subdivisions, which may be described as follows:

1. Water may be taken from the heads of streams by laying pipes right up to the springs, to convey it away for supply without any intermediate storage, as in the case of Lancaster. This is a source which in some sense belongs to the two classes, for the water is taken just as it ceases to be underground water, and is being delivered on to the surface above ground.

2. It may be obtained from a natural lake like Loch Katrine, as in the case of Glasgow.

3. It may be collected from a high-lying watershed area, by impounding a number of small streams in artificially constructed reservoirs, as is done for the supply of Manchester.

4. It may be taken from a large river flowing past the town, and is done in the case of the Thames and Lea for the supply of London.

The second class (*b*) is not divisible in the same way as (*a*), but may be taken as embracing supplies of water obtained from many varieties of geological stratification, such as chalk, oolites, coal measures, millstone grit, magnesian limestone, Bagshot sands, and many others.

All water, when discharged upon the

earth as snow or rain, is practically pure, but its character is very soon changed by the material it comes in contact with on the surface, or in passing through underground fissures and channels. Take, for example, the rain which falls upon the chalk downs of Sussex, or any other similar geological area. It sinks at once beneath the smooth and rounded surface, and percolates through innumerable minute cracks or larger fissures, dissolving away the chalk which it touches, and finally issues naturally in springs along the coast, or is pumped out artificially, a water which contains from fifteen to twenty-five grains per gallon of carbonate of lime.

Such an alteration in character depends, of course, upon the nature of the rocks which the water traverses, some rocks being easily soluble, others not.

The taking up of lime or magnesia in this way has the effect of rendering the water "hard," that is, increasing its soap-destroying properties. For many manufacturing processes this is a most undesirable quality, and we therefore find that many of the important industries of the country are located in districts where soft water is easily procurable.

The following are the formations which yield, as a rule, soft water: Igneous, metamorphic, Cambrian, silurian (non-calcareous), Devonian (non-calcareous), millstone grit, coal measures (non-calcareous), lower greensand, London and Oxford clay, Bagshot sands, non-calcareous gravels.

On the other hand the following geological formations almost invariably yield hard water: Silurian (calcareous), Devonian (calcareous), mountain limestone, coal measures (calcareous), new red sandstone, conglomerate sandstone, lias, oolites, upper greensand, chalk.

The manufacturing towns of Yorkshire and Lancashire obtain their supplies from sources which, even if the water had passed underground, would leave it comparatively soft, but this quality is fully secured by the character of the works, which consist of large reservoirs impounding the water which has principally run merely over the surface. For dietetic purposes, the quality of hardness, if not excessive, that is if it does not exceed twelve grains on Dr. Clark's scale (equivalent to twelve grains of bi-carbonate of lime per gallon) is not considered objectionable on physiological grounds. For ordinary domestic purposes and especially for personal washing and cleaning generally, soft water is infinitely preferable to hard, both in respect of comfort, efficiency, and economy.

Taking into account all the purposes for which water is used, it can hardly be questioned that a pure soft-water supply is, on the whole, preferable to a pure hard-water supply. The term "pure" is here used to imply the absence from the water of organic impurities as distinguished from the dissolved inorganic matters which have before been referred to. Except at producing hardness, the inorganic matters usually found in water are practically harmless; but organic pollutions may be of the most disgusting and dangerous character, those, for instance, which are the result of contamination with town sewage or of cesspool manure.

It is to avoid the risk of such pollution that many towns have in great measure been led to seek their sources of supply on elevated moorlands, above the level at which arable cultivation is carried on, and where it follows that there are no towns or villages, and the scattered population is very sparse. In this country the plough is rarely seen above the 800-feet contour, and, as it will not pay to cart manure to such an elevation, these high lands are merely used for the pasturage of sheep and the rearing of grouse.

Water obtained from such sources is practically, therefore, in the condition in which it falls from the clouds as snow or rain. The only impurity it may contain is a little organic matter derived from passing over the peaty soil, which often occurs on high moorlands, especially where the summits are broad and comparatively flat. This contact with peat and with growing heather gives a stain to the water to such an extent that, when seen in deep reservoirs, it is like dark coffee.

As seen in an ordinary white glass bottle or tumbler, the tinge is rarely deeper than a very faint straw color. There is nothing harmful in this coloring matter, because it is of purely vegetable origin, and to some extent it may be removed by storage in open reservoirs,

or running in open channels exposed to the air.

Many towns are so located in this country that it is practically impossible that they should obtain pure water supplies from elevated watersheds, on account of the enormous expense that would be entailed in the construction of the necessary works. Such places must be content to be supplied from rivers in their immediate neighborhoods, and which, having run their courses through many miles of highly manured lands and past thickly populated towns and villages, contain water which has necessarily become polluted by the washings from the lands and the sewage from the towns. Such sources as these would be inadmissible, but for the great rehabilitating process which nature silently carries on in a river, and to which chemists apply the term "oxidation." In this wonderful process the polluting organic matters which the water contains are converted by the agency of oxygen into harmless inorganic salts, and the water again becomes fit for the use of man.

This statement must, however, not be made without some reservation and explanation, because chemists of the very highest standing are not agreed as to the extent to which rehabilitation of the water is carried. This has, in fact, become quite a burning question, and the battle has been fought long and frequently over the water which is taken from the Thames, and delivered for consumption by the inhabitants of London.

The difference of opinion is now narrowed down into a small compass, and to outsiders it would appear that there is a chance, sooner or later, an agreement may be come to between the authorities.

As representatives of the two sides may be named Dr. Frankland and Dr. Meymott Tidy. Dr. Frankland admits that oxidation is effective in burning up, or converting into a harmless condition, even such foul contaminations as human sewage, if this is in a normal or healthy condition; but he contends that the virulent zymotic diseases are propagated by organized germs contained in the sewage which are indestructible, and which may travel scores of miles in a running stream without being deprived of their fatal potency.

Dr. Tidy contends, on the other hand, that there is no evidence of the existence of these animated germs, and affirms that a run of a few miles in a river fully oxygenated, and in which the pure water bears a sufficiently high ratio to the polluting matter, will suffice to render such water again fit for human consumption.

Dr. Frankland's theory is naturally a disquieting one, and his opponents certainly have facts in their favor, for London is undoubtedly one of the healthiest cities in the world, and its inhabitants have never been known to suffer from disease induced in the way suggested.

The "germ" theory is, however, making steady advances under the investigations and researches of competent men, and it is to be hoped and expected that if the historic germ is at last discovered, and exhibited to the incredulous gaze of Dr. Meymott Tidy, he, or some of his *confreres*, may speedily discover a method of scotching it before it has time to do any mischief.

It may now be convenient to describe shortly a few typical examples of the utilization of the different sources of supply which have been thus generally referred to.

I. Take first, such a case as that of Lancaster, whose works supply a population of between 30,000 and 40,000. The town is situated on the River Lune, about seven miles above its junction with Morecambe Bay, and is built upon a site which, rising from the river, varies in elevation from 15 to 200 feet above Ordnance datum, or mean tide level. The water is obtained from the high moorlands of Wyresdale, at a distance of eight or ten miles from the town, in a south-easterly direction. These fells, as they are locally called, constitute the extreme north-easterly portion of the watershed of the River Wyre, a small river which also falls into Morecambe Bay near the town of Fleetwood. That portion of the fells which is secured by Act of Parliament as a source of water supply for Lancaster, has an area of 2,700 acres, and an altitude varying from 850 to 1,800 feet above the sea.

The geological formation of the gathering ground is millstone grit, covered with scant herbage suitable for sheep pasturage, and heather. Interstratified with the beds of permeable grit stone there are layers of impervious shale

which, at various levels, throw out the water percolating downwards from the surface, in the shape of springs, and a number of these springs have been intercepted by small pipes communicating with mains laid along the hill side, and leading their combined waters to the south-west corner of the reserved area.

One of these mains forms part of the original works constructed under the superintendence of Sir Robert Rawlinson, C. E., C. B., in the year 1852; the other, which runs (broadly speaking) parallel to the first, but about 200 feet lower down the hill side, was laid six years ago, as part of an extension carried out by the writer.

The water derived from these is of necessity of the purest possible character, for the rain which feeds the springs falls upon the clean open moorland, and sinks at once into the millstone grit rock, in which it finds nothing to dissolve and cause hardness, and nothing to organically pollute.

The water issues from the springs in a bright sparkling condition, at a constant temperature of about 45° F.; it contains only one grain in 15,500 of solid matter, and its hardness is under 1° on Clark's scale.

This may be fairly regarded as an ideally perfect source of supply, and it has been an inestimable boon to the inhabitants, especially as it replaced water obtained from shallow wells in the town, polluted in the vilest possible manner by percolation from numberless foul and reeking privy pits and middens.

Between the fells and the service reservoir, which is situated on the town moor 240 feet above Ordnance datum, the country is intersected by several valleys, across which the water is conveyed in iron pipes.

At two intermediate points the pressure is broken by a small covered tank, and the water is never exposed to the open air from the time it sinks into the ground as rain or snow, and is drawn from the consumer's taps in the town.

Perhaps it may be as well to explain here that, when water is obtained from elevated watershed areas of this character, Parliament almost invariably insists upon "compensation" being made to the river for such abstraction. This compensation is secured by the construction of reservoirs somewhere upon the main river or its tributaries, in which water is stored in time of flood, and given out in a constant stream in times of dry weather, the assumption being that floods are utterly useless, if not damaging, to riparian owners and mill owners, whilst it is of advantage to every interest to have the dry weather flow increased in volume.

Thus, in the Lancaster case, whilst the Corporation have the right to take 2,000,000 gallons a day from the springs for the use of the town, they were put under the obligation to construct upon the River Wyre a reservoir capable of holding 185,000,000 of gallons, from which the millowners have the right to draw water according to their needs during the summer months. By means of such works, all the parties concerned are very greatly benefited.

II. The second type of utilization of sources which may be referred to, is that which is exemplified on so magnificent a scale in the works supplying Glasgow, and constructed from the designs and under the superintendence of Mr. John Fredrick Bateman, C. E.

In this case, advantage is taken of three natural lakes, viz., Loch Katrine, Loch Venachar and Loch Drunkie. The watershed area draining into these lakes is 45,800 acres in extent, and consists of unpolluted sparsely populated moorlands, the geological formation being of the silurian age.

Loch Katrine has a water surface of 3,000 acres, Loch Venachar 900 acres, and Loch Drunkie 150 acres. They are all of course supplied by the rain which falls upon the 45,800 acres, and as a considerable proportion of this area is of a peaty character, the streams which run down the mountain sides are frequently as dark as London Porter. By the deposit of the heavier parts of the peaty matter, and the bleaching action of the air, the water is drawn from Loch Katrine with only a faint tinge of color.

The two smaller lakes are utilized as compensation reservoirs, the artificial storage necessary being obtained by raising the original normal level of Loch Venachar 5 feet 8 inches with power to draw it down 6 feet, and by raising Loch Drunkie 20 feet, the raising in both cases

being done by masonry dams across the outlet valleys, furnished with draw-off sluices.

The storage for the supply of Glasgow is obtained by works which raised the normal level of Loch Katrine 4 feet and admit of drawing down 3 feet. Its capacity is, therefore, 3,000 acres of area, by 7 feet in depth, equivalent to nearly 1,000 million cubic feet, and competent to furnish 50 million gallons a day during a four months' drought.

The water surface in Loch Katrine is 360 feet above mean tide level at Glasgow. The conduit conveying the water to the city commences on the south side of the lake, about three miles from its western extremity, and runs generally in a southerly or south-westerly direction. At 26 miles from the Loch it discharges into an artificial reservoir of 70 acres in extent, and holding 500 million gallons near Mugdock Castle, the top water of this reservoir being 311 feet above mean tide at Glasgow. Two lines of three feet cast-iron pipes, one seven miles long and the other eight miles, convey the water to the city.

For thirteen miles out of the 26, between Loch Katrine and Mugdock, the conduit is formed by tunneling through very hard rock, such as whinstone, gneiss, and mica slate; the tunnels being seventy in number, nine miles of the remaining length is "cut and cover" work, and the rest consists of cast-iron or wrought-iron pipes across valleys.

The advantage of such a source of supply as Glasgow's is the facility and small cost with which the storage capacity necessary to furnish the requisite daily quantity for consumption and compensation is obtained.

In Loch Katrine, the narrow outlet from the lake had only to be dammed up four feet, requiring artifical works of the simplest character, entailing no risk or contingency in their execution. Having a flat area 3,000 acres in extent to begin with, a simple plank one foot high would have sufficed to impound 816,000,000 gallons. The desirability of securing such a reservoir site as this can only be fully appreciated by those who have had the responsibility and anxiety of forming large storage reservoirs, by the construction of high embankments across valleys. The relative amounts of labor and outlay in such reservoirs, and in cases like Loch Katrine, will be better realized in considering the next type.

III. The third type of works for the utilization of mountain watershed sources of supply is well exemplified in the Longdendale valley, where a number of reservoirs have, during the last thirty years, been constructed for the supply of Manchester. Here, instead of having a level plain 3,000 acres in extent as in Loch Katrine, upon which to commence as the bottom of a reservoir, was a valley with a fall along the bed of its main stream—the Etherow—of between 60 ft. and 70 ft. in a mile. Across this valley five embankments have been constructed of earthwork, one above another, forming five lakes with a combined water surface area of 462 acres. Beginning from the lowest part of the valley, the following is a list of the reservoirs, viz:

	Height of Bank. Feet.	Water area. Acres.	Capacity. Gallons.
Bottoms.....	66	50	407,000,000
Vale House....	55	63	343,000,000
Rhodes Wood..	75	54	500,000,000
Torside.....	100	160	1,474,000,000
Woodhead.....	80	135	1,181,000,000
Total.....	376	463	3,905,000,000

These embankments, which cost something like £100,000 apiece, have an aggregate height if placed one above another of 376 feet, and the quantity of water they impound is 3,905 million gallons. The raising of the water surface of Loch Katrine 5 feet would create the same amount of storage. The watershed area supplying these reservoirs is 9,300 acres, and the geological formation is millstone grit. The gathering ground is a portion of the western slope of the "backbone" of England, otherwise the Pennine range, upon which, over its whole length on both sides, many similar works are located for the supply of the manufacturing towns of Lancashire and Yorkshire. The rocks in this district are very much fissured and broken, and the rain falling upon the higher grounds percolates below the surface and re-appears as springs at lower levels. Advantage is taken of this by conducting the spring water along special channels into the Rhodes Wood reservoir, from

which the supply is taken by a conduit to the town.

Although the quantity of water yielded by the whole ground is that due solely to its area and the rainfall upon it, the fact of there being these springs renders it more valuable, because it implies that water which would have run off a district composed of harder and less pervious rocks, is here absorbed into the mass which thus acts as so much storage or reservoir space. The effect of this is to increase the dry weather flow of the streams, and to furnish water which is clear, cool and colorless. The average annual rainfall upon the 19,300 acres is about 50 inches, and the works utilizing this area are competent to provide 38,000,000 of gallons per day, of which 13,500,000 have to be delivered into the stream below the reservoirs as compensation water. Besides the five reservoirs above named, there are other large impounding and service reservoirs at Godley, Denton, Gorton and Prestwich. In the construction of these works enormous difficulties have been encountered, and at Woodhead, the highest reservoir of the series, the embankment, as at first made, was not watertight, so that a second trench had to be put down in which to build the puddled wall, and so much were the measures disturbed and distorted, that on the south side of the valley this trench had to be excavated to 167 feet below the surface of the ground, before sound and tight material was reached upon which the wall could be based.

The three types of works thus described may fairly be said to exhaust the methods of obtaining water from sources situated on elevated mountain gathering grounds. They are good examples of the gravitation system of supply, by which water is delivered at high pressure above the highest parts of the towns without any artificial pumping being required, the sun having done this work in the process of evaporation.

IV. We will now consider a case where the town to be supplied is at such a distance from high ground that the cost of bringing it through conduits or pipes by gravitation is prohibitive.

Take a town built along the banks of a river anywhere above the range of the tide. If this river flows through an agricultural district, and is thus not polluted by manufacturing refuse, and not seriously by either manure or sewage, it may be adopted as the source of supply. In this case the water will have to be lifted by artificial means to such an elevation as is necessary to command the whole town.

The water will also require filtration, because in running its course through the country the river receives the washing from the land, and in times of heavy rain, at all events, the water will be discolored and turbid through the presence of suspended matters.

The works for the supply of London are, in great part, of this character, the rivers Thames and Lea being the two sources.

Three hundred years ago water was obtained from the Thames at London bridge, and pumped by means of a waterwheel under one of the arches through wooden pipes into the streets and houses in the neighborhood. These works were continued in operation for 200 years, and were supplemented early in the 17th century by other pumping stations, taking water from the Thames at Charing Cross, Battersea, Vauxhall, and Hammersmith, all within the range of tidal influence.

In 1848 the Lambeth Water Company obtained powers to go into the non-tidal portion of the river above Teddington Lock, and by the year 1851 they were in a position to deliver water by means of a large steam-pumping establishment erected at Seething Wells.

In 1852 an Act was passed which made it unlawful for any company to supply water taken from the river below Teddington Lock, or from any of the tributaries within the tidal range. This led, finally, to all the companies drawing water from the Thames, so re-arranging their works as to have their intakes above Moulsey Lock, in order to be above the junction of the River Mole, which frequently brings down very dirty water.

Owing to the changes in the points of intake, the works of the London companies are divided into portions at great distances apart. Thus the Southwark and Vauxhall Company have at Battersea the reservoirs, filter beds, and pumping machinery constructed for the purpose of taking in water from the river at that point. They are well known to all Lon-

doners by reason of the tall stand-pipes which form a prominent object in the view from the trains running out of Victoria station.

These works are of so costly and extensive a character, that they could not be abandoned when the source of supply was changed to Hampton, 21 miles higher up the river, but the water abstracted there is pumped down to them through large cast-iron mains, to be filtered and distributed by the original machinery and mains.

In the case of the Lambeth Company, the water is taken from the Thames at Molesey, and sent down to Surbiton, which is the site of the filtering and pumping station, through a large brick conduit by gravitation.

From these circumstances none of the London works are good examples of the type now under consideration; but the following description will explain the nature of the works required for the utilization of such a source as the Thames above London.

First of all, then, provisions must be made to meet the difficulty of the water arriving at the intake in times of flood in a state of great turbidity or muddiness. This is met by the provision of large reservoirs, which are always kept full so long as the water is coming down in good condition, and the inlets into the river are closed, and they themselves are drawn upon when the water of the river is turbid.

These reservoirs used to be of smaller capacity than at present, and were worked as subsidence tanks, that is to say, the water (which might be somewhat turbid) was let in at one end and drawn off only from the surface at the other, the suspended matters causing the turbidity subsiding to the bottom during the water's slow passage through the tanks.

In London, since the works of the several companies have come under the official supervision of Sir Francis Bolton, very large sums of money have been spent in increasing the efficiency of these subsiding tanks by greatly augmenting their capacity, and practically changing their character into that of storage reservoirs.

In some of the works, these reservoirs are constructed at such a level that the water from the river flows into them by gravitation; in others they are elevated above the ground, and the water is pumped into them. In either case it is next delivered on to the filter-beds, the construction of which is shown very clearly in the most interesting pavilion erected in the Health Exhibition by the water companies. These filters consist of reservoirs or tanks made either by excavation in the ground or partial excavation, and partial embanking, as circumstances may dictate, having their sides sloped and pitched, or of vertical brick, stone, or concrete walls. The bottom is formed in many different ways, but it is always furnished with a number of open-jointed or perforated pipes or drains into which the water can pass, and by which it may be conveyed away to a pure-water chamber or pump-well. Upon this floor the filtering material is placed, and consists of clean stones, flints, gravel, shells, and sand, arranged with the largest sized material at the bottom and the finest at the top.

Probably the oldest style of filter shown in the Exhibition is that designed by the late James Simpson, C.E., for the Chelsea Company, and it contains all the materials above-mentioned, and has a total depth of 6 ft. 3 in.

As, however, the really operative and effective portion of the filter is the sand, modern practice is tending in the direction of diminishing the depth of filtering material, and of omitting entirely several of the strata originally used. For instance, the New River Company's engineer exhibits a filter composed solely of 2 ft. of sand resting upon 6 in. of gravel, the total depth being only 2 ft. 6 in. In working the filters, the water is brought from the storage or subsiding reservoir on to the top of the sand, and stands from 2 to 3 ft. above its surface. It then percolates downwards through the filtering material into the drains below, and is run away to be pumped for distribution.

The speed of filtration may be adjusted by the head under which the filter is worked, that is, the difference in level betwixt top water and the draw-off. In some cases this is only 2 or 3 inches. The speed at which the water should pass vertically downwards through the sand used to be stated as 6 in. per hour, which gave 675 gallons per square yard per day of 24 hours, but the London companies

are now not filtering more than 450 to 500 gallons, or from 4 to 4½ in. per hour.

The matter which is arrested by the filters consists principally of finely divided mineral matter washed from the surface of the land, of some vegetable and a trace of animal matter. These impurities are caught almost entirely in the top half-inch of the sand, which in course of time they choke and render impervious. The filter is then put out of use; the water is drawn off, and a skimming of the fouled sand is carefully removed and washed in apparatus which separates the light muddy matter and leaves the clean sand which is again put upon the filter. Of course, the washing process involves some loss of sand, and periodically additions have to be made of new material. After filtration, the water is in a fit condition to be pumped and distributed to the consumers.

Thus far we have been dealing with "above ground" sources of supply, obtained either by gravitation or by artificial pumping, under the four heads numbered—(1) being springs at high elevation, without storage; (2) being surface water from moorlands drawn from natural lakes; (3) being surface water from similar watersheds, impounded in artificial reservoirs; (4) being river waters filtered, and artificially pumped for supply.

There are in this country a few examples of hybrid schemes, that is, where water from comparatively low agricultural land is impounded in large reservoirs, and where it has to be subsequently filtered and pumped for distribution in the district. There may also be cases where water collected at a sufficient elevation to supply a town by gravitation has to be filtered before delivery.

We now come to the underground sources of supply, and one or two examples will suffice to explain how these are made available. We need not go far from home to learn all about one of the most important of these underground sources, for it lies under our feet in the chalk forming one great feature of the London basin.

London is actually built upon the tertiary deposits, which consist of Bagshot sands, London clay, and the sands and mottled clays of the lower strata; but underlying all these is a mass of chalk having the southern edge of its outcrop on the north of London about Hatfield, and the northern edge near Royston, and its southern outcrop extending from Croydon to Merstham. On the west the chalk reaches as far as Devizes, and on the north-east to near the coast of Norfolk and Suffolk. Portions of this vast area are no doubt covered by impermeable drifts of varying character, but there is still a very large tract of country upon which the rain which falls sinks below the surface, and goes to charge the great underground chalk reservoir below.

Possibly, the term "reservoir," though a common one, is a little misleading as applied to the chalk, because for water supply purposes, a large proportion of that which percolates into its mass is not recoverable by ordinary means. It is the water which circulates through the cracks and fissures which is really available, and not that which is held in the minute capillaries of the mass. Some chalk will contain 20 per cent. of its own bulk of water, and yet will not yield a drop of this under ordinary conditions.

Of the water which thus sinks into the chalk, a large portion finds its way out again into the bed of the river, another portion appears in the shape of large springs, such as those at Carshalton and Croydon, which go to form the River Wandle, by flowing over the edge of the impervious tertiaries.

Very rarely are there any streams where the chalk itself comes to the surface, but after heavy and continuous rains, streams do appear and flow for a time, and these are known as "bournes." As the chalk is 500 or 600 feet thick, a very large quantity of water is, however, left in it below the level of any of these natural outlets, and this water can be obtained in London by sinking wells through the overlying impervious beds of London clay, and allowing the water to rise, as in an artesian well.

There are a large number of wells in the London basin, and one of the metropolitan water companies, the Kent, obtains its supply exclusively from such wells. The ordinary practice is to sink a well from five feet in diameter upwards, and line the same either with brickwork or cast-iron cylinders down to the chalk. This will pass through superficial gravels, blue clay, bands of sand, mottled clay,

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There are in this country a few examples of hybrid schemes, that is, where water from comparatively low agricultural land is impounded in large reservoirs, and where it has to be subsequently filtered and pumped for distribution in the district. There may also be cases where water collected at a sufficient elevation to supply a town by gravitation has to be filtered before delivery.

We now come to the underground sources of supply, and one or two examples will suffice to explain how these are made available. We need not go far from home to learn all about one of the most important of these underground sources, for it lies under our feet in the chalk forming one great feature of the London basin.

London is actually built upon the tertiary deposits, which consist of Bagshot sands, London clay, and the sands and mottled clays of the lower strata; but underlying all these is a mass of chalk having the southern edge of its outcrop on the north of London about Hatfield, and the northern edge near Royston, and its southern outcrop extending from Croydon to Merstham. On the west the chalk reaches as far as Devizes, and on the north-east to near the coast of Norfolk and Suffolk. Portions of this vast area are no doubt covered by impermeable drifts of varying character, but there is still a very large tract of country upon which the rain which falls sinks below the surface, and goes to charge the great underground chalk reservoir below.

Possibly, the term "reservoir," though a common one, is a little misleading as applied to the chalk, because for water supply purposes, a large proportion of that which percolates into its mass is not recoverable by ordinary means. It is the water which circulates through the cracks and fissures which is really available, and not that which is held in the minute capillaries of the mass. Some chalk will contain 20 per cent. of its own bulk of water, and yet will not yield a drop of this under ordinary conditions.

Of the water which thus sinks into the chalk, a large portion finds its way out again into the bed of the river, another portion appears in the shape of large springs, such as those at Carshalton and Croydon, which go to form the River Wandle, by flowing over the edge of the impervious tertiaries.

Very rarely are there any streams where the chalk itself comes to the surface, but after heavy and continuous rains, streams do appear and flow for a time, and these are known as "bournes." As the chalk is 500 or 600 feet thick, a very large quantity of water is, however, left in it below the level of any of these natural outlets, and this water can be obtained in London by sinking wells through the overlying impervious beds of London clay, and allowing the water to rise, as in an artesian well.

There are a large number of wells in the London basin, and one of the metropolitan water companies, the Kent, obtains its supply exclusively from such wells. The ordinary practice is to sink a well from five feet in diameter upwards, and line the same either with brickwork or cast-iron cylinders down to the chalk. This will pass through superficial gravels, blue clay, bands of sand, mottled clay,

&c., and sometimes on the top of the chalk a band of flints will be found. Below the bottom of the well a boring is then made from 4 inches up to 15 or 18 inches in diameter, and lined with iron whilst in soft or much broken chalk, and left unlined where the material is more compact.

In those parts of London which are not elevated many feet above the level of the river, the water rises to very near the surface of the ground, and in some cases overflows; but wherever large quantities are required, resort must be had to artificial pumping so as to lower the level of the water in the well, and thus open out a larger cone of exhaustion in the chalk. Favorably situated chalk-wells yield as much as 2,000,000 to 3,000,000 gals. a day.

In many cases wells and mere borings have been put down right through the chalk to the upper greensand or gault below, and have yielded only a very small quantity of water. This arises from the fact before referred to, that the water circulates freely only in the cracks and fissures, and if some of these are not cut into by the boring, little water is obtained. The most certain way, therefore, of insuring a supply from the chalk, is by sinking a well down to below the permanent level of saturation, and then driving headings or adits in various directions, for the purpose of reaching some of these fissures. Many of the towns along the south coast of England are supplied by works of this character. It has been found that where the chalk of the South Downs has been undisturbed and is unfaulted, there are large vertical fissures which run, broadly speaking, from north to south, that is, at right angles to the coast. Along these fissures the water travels freely, and has its outlet at the base of the cliffs on the coast, and may be seen running down the beach in many places into the sea.

Parallel to the coast, the water is found to lie with its surface nearly horizontal, because of these permanent outlets, but on lines at right angles to the coast, the surface of the water rises rapidly inland, on a nearly uniform slope, so much so that, at six miles from the coast, it stands more than 200 feet above mean tide level. Advantage has been taken of these conditions at Brighton, and other places similarly situated, to sink wells and drive headings parallel to the coast, at about the level of low water.

At Brighton there are two such stations, one at Lewes-road, on the east, and another at Godstone Bottom on the west. These wells are both about a mile and a quarter from the sea, and headings are driven to a total length east and west, from Lewes-road, of 2,400 feet; and at Godstone Bottom, of 1,300 feet. In the first case, fissures are met with about every 30 feet, but as a rule these are small, and do not yield more than 100 to 150 gallons a minute. In the latter they are further apart, but some of them yield 700 or 800 gallons a minute, or over a million gallons a day. This water, being intercepted by the headings, is led to the respective wells, where, by means of suitable steam machinery, it is pumped up to the several service reservoirs supplying the different zones of the town.

The water so obtained requires no filtration. It is bright and sparkling, but of necessity hard, and although not objectionable for dietetic use, it is not well fitted for cooking or cleansing purposes, and would be utterly unsuitable for the manufacturing processes of Lancashire and Yorkshire, though thoroughly well adapted for paper-making.

In addition to the chalk, good supplies of underground water are obtained in the South of England from the Hastings sands and the oolites, and in the north from the new red sandstone, magnesian limestone, and other formations; but in all cases the works required for the utilization of these sources are very similar, consisting of wells, borings, and adits, with competent pumping machinery.

Comparing very generally "above-ground" supplies by gravitation with "under-ground" supplies involving pumping, there are advantages and disadvantages on both sides which may shortly be summarized as follows:

"Above-ground" Gravitation Sources.

Advantages.	Disadvantages.
1. No pumping.	1. Distance from place to be supplied.
2. No filtration.	2. Peaty stain.
3. Softness.	3. Costly and somewhat risky impounding reservoirs.
4. Low charges for maintenance.	4. Large works involved to provide water "compensation."

"Under-ground" Pumping Sources.	
Advantages.	Disadvantages.
1. Proximity of source to place to be supplied.	1. Annual charges for pumping.
2. Low first cost.	2. Hardness (generally.)
3. Few structural contingencies attending works.	
4. No filtration.	
5. No Compensation for abstraction of water.	

Water Supply for Fire Extinction.

BY J. H. GREATHEAD, M. INST. C. E.

When it is considered how vast is the havoc wrought by fire every year, and that we depend upon a supply of water, in all cases, to prevent much greater ravages, the importance of this subject will be at once recognized.

In London alone, it has been calculated on reliable data that the destruction of property in 1882 amounted to at least 2¼ millions sterling, and last year it was probably more; and it has been stated by a very good authority, Mr. Edward Atkinson, of the Boston Manufacturers' Mutual Insurance Company, that the losses by fire in the United States and Canada, in the five years ending January 1st, 1879, amounted to 82½ millions sterling, while the cost of insurance companies and fire departments in the same period amounted to 55,000,000 more, or together to an average of 27,000,000 sterling per annum.

It is difficult for the mind to grasp such figures; the last, however, is about equal to the whole rateable annual value of the metropolis.

If such losses as these were inevitable, it would be of little profit to refer to them, but it is because I believe them to be to a large extent preventable that I have ventured to bring the subject of water supply for fire extinction before you.

In the remarks which I am about to make I purpose to refer largely to the case of this metropolis, as being likely to add additional interest to the general subject, and because the reasoning which applies to this will apply in a greater or less degree to all other similar cases.

It may be useful at once to define what are the requirements necessary to be fulfilled in a water supply for fire extinction purposes.

In order to reduce, as far as possible, the destruction of life and property by fire, the fire extinguishing service should have at hand—

(1) A copious supply of water.

(2) In close proximity to the property.

(3) Easily accessible.

(4) Having sufficient and reliable pressure.

In nearly all cities the water supply has been introduced and distributed without reference to the fulfillment of these conditions. The quantity of water required for the extinction of fires is so infinitesimal as compared with the quantity required for all other purposes, that, except where the conditions have been naturally favorable, the water service has been introduced, devoid of some, at least, of the qualities necessary to fit it for fire purposes. The result, in such cases, has been that mechanical contrivances have had to be provided in order to make good whatever deficiencies existed in the supplies, and dwellers in cities have become familiar with fire-plugs and fire-engines.

There are, however, some cities in this country where, the conditions having been favorable, the authorities having control of the water supplies have wisely availed themselves of Nature's gifts.

The most notable instances are those of Glasgow, Dublin, Liverpool, and Manchester. In all these cases the water supply is almost entirely by gravitation, and the result is that over the greater and most important parts of the cities there is a good pressure, and a copious supply of water which has been made easily accessible by the introduction of numerous hydrants in close proximity to the property in each place. Here, then, we have, as nearly as may be, in four of the most important cities of the United Kingdom, a fulfillment of the necessary conditions (as to water supply) for fire extinction.

An ordinary hydrant may be shortly described as a stop-cock on a water-pipe or main, to which hose may be attached for fire extinction or other purposes. If for fire-extinction, without the intervention of a fire-engine, the hose will, at its other end, be provided with a branch and nozzle. Upon opening the stop-cock the water from the main, or pipe,

will issue from the nozzle as a jet. The height of the jet will depend upon the pressure in the main, the quantity of water available, the length of hose employed, and the size and shape of the nozzle.

A fire-plug is a wooden plug driven tightly into a socket or opening in a water pipe under the road. When water is required for fire extinction the plug is withdrawn, and the water issues from the opening, either into the street, where it is usually received by a portable tank, or into a stand pipe inserted in place of a plug. It is obvious that plugs cannot be used where the supply is constant with a good pressure, and they have not been placed upon the constantly charged mains (the best existing supply for fire extinction) in the metropolis. Several forms of hydrants and a fire plug and stand pipe may be seen in the Water Companies' Pavilion in the Exhibition.

In order to obtain a good jet from a hydrant, it is necessary that the pressure of water at the hydrant, while flowing, should be about 65 lbs. per square inch. This will provide for overcoming the friction of the water in passing through an average length of hose, and will give a jet about 80 feet high from an inch nozzle. From the elaborate reports of the chief officer of the Dublin Fire Brigade, which he has kindly furnished to me, it appears that all the fires in Dublin, except those extinguished by small hand pumps, are put out by jets direct from the hydrants, and that the prevailing pressure is about 60 lbs. per square inch.

So much has been written and said about hydrants, and the advantages to be derived from their use, during the last twenty years, that it is hardly necessary for me to discuss their merits as compared with fire plugs. It is gencrally conceded that in all cases, whatever the water supply may be, whether constant or intermittent, high pressure or low, hydrants are superior to plugs as a means of letting the water out of the pipes. But it has been contended that so long as it is merely a question as between hydrants and plugs, the advantages of the former over the latter are not sufficiently great to justify any large expenditure upon them. When, however, the question becomes one as between hydrants and fire-engines, a wider view becomes necessary. Hydrants with a constant and copious supply and good pressure of water, are recognized as being incomparably better agents for extinguishing fires than fire engines, and the result of the introduction of hydrants into Manchester may be given in illustration. Mr. Bateman, the eminent engineer of the Manchester Waterworks, has stated publicly, on more than one occasion, that the introduction of hydrants with a good pressure of water has resulted in a reduction of the losses from fire in Manchester to a small fraction (viz., one-seventh) of what they were before the introduction of the hydrants. And, according to the report of Captain Tozer, the Superintendent of the Manchester Fire Brigade, the amount of property destroyed has only averaged 4.3 per cent. of that at risk during the last ten years, while it will be seen presently that in places having no efficient hydrant services the losses are many times greater. In Liverpool the fire brigade is a branch of the police. The water supply is mainly by gravitation from reservoirs (from 400 to 600 feet above the low parts of the town), and there are numerous hydrants. There are 3 steam and 14 manual fire engines. The population in 1881 was 548,650, and the area is 8¼ square miles. Of the 180 firemen, 170 do regular police duty. The annual cost of the brigade (average of three years, 1880–1–2) was £5,325, or £9 14s. per 1,000 of the population. The average annual number of fires in the same period was 219, but the loss by fire was not ascertained.

In Glasgow there is a good supply of water by gravitation; there are about 5,000 hydrants, and the majority of the fires are extinguished direct from the mains. There are 3 steam and 17 manual fire-engines. The 66 officers and firemen are supplemented by an auxiliary force of 52 policemen. The area of the city is 9½ square miles, and the population in 1881 was 510,816. The cost of the brigade to the ratepayers in 1882 was £5,266, or £10 6s. per 1,000 inhabitants; while the average annual loss from fire in the same period was £110,000, or about £215 per 1,000 of the population.

In Manchester the supply is also by gravitation from resrvoirs at a considerable elevation (200 feet to 600 feet

above the Exchange), and there is a constant high-pressure supply. There are about 17,000 hydrants in the city and suburbs. Two steam and five manual fire engines are retained, but are seldom used. The population in 1881 was 341,500. The area of the city is $6\frac{3}{4}$ square miles, but the fire brigade extend their operations beyond the city. There are sixteen stations, and the annual cost to the ratepayers for the fire brigade is £3,547 (on an average of the three years, 1880–1–2), or equal to £10 8s. per 1,000 of the population. The average estimated annual value of property destroyed in those three years was about £80,000, or about £235 per 1,000 of the population.

In Dublin the supply of water is again by gravitation, and the pressure varies from about 40 lbs. to 80 lbs., being generally 60 lbs. when the water is flowing through the hydrants. There are numerous hydrants, and though there are 2 steam and 3 manual engines, they do not appear to have been used in the three years (1880–1–2), within the city. The brigade consists of 32 officers and men. The population in 1881 was 249,602, and the area of the city is 6 square miles, but the operations of the brigade are not confined to that area. The average annual cost of the brigade for expenses and wages (for the three years 1880–1–2) was £3,286, or about £13 3s. per 1,000 of the population. The estimated value of property destroyed averaged £31,144 per annum, or about £125 per 1,000 of the population.

In Birmingham the whole of the water supply is pumped, therein differing from the cases already referred to; but a system of fire hydrants has been recently introduced. The population (average of 1882 and 1883) is 411,690, and the area 13 square miles. The fire brigade consists of twenty-seven officers and men, and there are two stations and eight police stations, with apparatus. One steam and five manual fire engines are retained, none of which were used for fire extinction in 1882, and engines were used twice only in 1883. The total water supply is $11\frac{1}{2}$ million gallons daily, with a pressure of 40 lbs. to 60 lbs. per square inch. The annual cost of the fire brigade to the ratepayers (average of 1882 and 1883) is £3,250, or £7 18s. per 1,000 of the population, while the average annual loss in the two years was £10,931, or £26 11s. 8d. per 1,000 of the population, and this loss was equivalent to 3 per cent. only of the value of the property "at risk."

In Paris the water supply is partly pumped and partly by gravitation. Street hydrants have, to some extent, been introduced. In certain cases, where the pressure is sufficient, they are used without the intervention of fire engines, but the water supply is not such as to admit of this being done generally. It is intended, however, to increase the number of hydrants to 8,000, and ultimately to make them universal, and to dispense with fire engines. The total daily supply of water is about 82 million gallons. The population is 2,269,000, and the area 29 square miles. The fire brigade, numbering 1,743 officers and men, is an armed force lent by the Minister of War for the special service, and it is not called out for purposes of war. There are 11 barracks, 10 steam fire, and 80 small stations in addition to 40 look-outs, and there are 12 steam and 80 manual fire-engines. The annual cost of the fire-extinguishing service is £86,600 (average of two years, 1883 and 1884), or about £38 3s. per 1,000 of the population; but this cost does not include the rent and repairs of the barracks, quarters, &c., which belong to the Prefecture of the Seine. The estimated annual average losses for the three years 1880–1–2, were £431,300, or about £122 10s. per 1,000 of the population.

Having now described the operations, and their results in cities having efficient hydrant services, I propose to direct attention to some of the more important of the cities having no such services, and more particularly to New York and London.

In New York the water supply is very copious but it has not sufficient pressure for fire purposes without the intervention of fire engines. Hydrants have, to some extent, been introduced, and, it is stated, with benefit, as permitting more speedy access to, and preventing waste of, the water. The total supply is, according to the report of the fire department, about 100 million gallons daily; the population in 1880 was 1,206,300, and in 1881 probably 1,240,000. The area served by the fire brigade is about 39

square miles. In 1882 there were 50 engine companies, and 19 hook and ladder company stations, besides lookouts, fuel depots, and store houses. There were 57 steam fire, but no manual engines. In the period 1880–82 the average force was 939 officers and men, and the average annual expenditure was £288,190, or £230 8s. per 1,000 of the population. In the same period the average annual fire losses were £880,000, or about £710 per 1,000 of the population. The quantity of water used by the fire engines was about 40,000,000 gallons annually in the period 1880–2, or about 1-900th part of the total supply.

In London the whole of the water supply is pumped, and the average pressure is quite inadequate for fire extinction without the intervention of fire engines. A large number of observations were made all over the Metropolitan area by the Board of Works in 1876, and it was found that the average pressure was only about 30 lbs. per square inch, when there was no extraordinary draught on the pipes, such as that required for fire extinction; and it is not surprising that this should be so. The pressure given by the water companies is that required by statute, or, otherwise, by the customers of the companies, and even if they desired to do so it might be doubted whether, in the words of the Select Committee of 1876–7, the companies would be "justified by their constitution in incurring expenditure for fire purposes," for which purposes alone would it be necessary for them to increase their pressure.

The quantity of water delivered for all purposes is sufficient to meet the demands for fire extinction. There are, according to Captain Shaw's reports, very few cases of short supply, and constant supply is being gradually extended voluntarily by the water companies. Hydrants have been put down by the corporation throughout the city, and connected directly by branches with the constantly charged mains of the New River Company, and they have on several occasions been found useful, though the pressure is not such as to admit of fire engines being dispensed with in all cases. A few hydrants have also been recently introduced by the Metropolitan Board of Works in other parts of the metropolis.

In the matter of pressure, however, as already stated, the general metropolitan water supply is undeniably deficient. There is a copious supply of water in close proximity to the property to be protected, but it cannot be brought to bear upon a fire without the intervention of fire engines.

The population of the metropolis in 1881 was 3,814.571, and the Metropolitan Board of Works area is about 121 square miles, including the city's one square mile. There are fifty-five land fire stations, 12 street, 127 fire escape, and 4 floating stations; and the brigade consists of 588 officers and men. The annual average cost of the fire brigade for the three years 1880–2 was £99,880, or £26 4s. per 1,000 of the population. It is somewhat difficult to arrive at the value of the property destroyed by fire in the metropolis, but a calculation based upon the contributions of the insurance companies to the support of the fire brigade, and upon evidence given by Captain Shaw and others before the Select Committee on the Fire Brigade in 1877, would make it appear that in 1882 the value of insured and uninsured property destroyed by fire was probably considerably in excess of 2¼ millions sterling, or about £588 per 1,000 of the population. As compared with the efficiently hydranted places already referred to, it will be seen that the cost of the fire extinguishing service, and the fire losses, are very high in London. This will be made very apparent upon an inspection of the appended Table A, which gives, in addition to the cost of the fire services and fire losses in the several places referred to, a statement of what the cost and losses would be in the metropolis, were the rates of cost and loss the same as in the other places.

It will be asked why the metropolis should have been allowed to remain, year after year, subject to the preventible drain of wealth indicated by these figures? The reply is, that the past and existing state of things have not been submitted to in ignorance or willingly, but the difficulties surrounding the subject in the metropolis have been practically insurmountable.

More than twenty years ago the Select

Committee on Fires in the metropolis directed attention to the extraordinary facilities for extinguishing fires then existing in Liverpool, Manchester and Glasgow, and to the efficiency and small cost of the fire services in those places; and, more recently, in 1876–7, the Select Committee on the Metropolitan Fire Brigade, having heard evidence as to the advantages of the hydrant systems referred to, recommended that hydrants should be put down in the metropolis at once wherever a constant supply was given, and that the water supply should be improved so as to give constant service everywhere and increased pressure. But it was found that to comply with these recommendations a permanent expenditure of £337,000 per annum beyond the cost of the fire brigade would be involved. Of this annual sum about £150,000 represented the increased cost of pumping alone; and since the quantity of water required for fire purposes is infinitesimal as compared with the quantity supplied for all other purposes, it is obvious that this expenditure of power, if the whole had to be pumped to the requisite height, would be out of proportion to the result obtained. I have made a calculation, based upon the relative quantities and upon the evidence given before the committee, from which it appears that for the purpose of discharging water through a hydrant upon a fire in this way, about 170 horse-power would be required for every gallon of water thrown. And there would be the attendant disadvantages that all the house fittings would have to be altered and strengthened, and the mains and pipes would have to be taken up, and relaid of greater size and strength, and at enormous inconvenience to the householders and the traffic in the streets; and the pressure would, in the greater part of the metropolitan area, be inconveniently great. This proposal also involved the great disadvantage that it could not be carried out until the water companies should have been ranged under one control.

As long ago as 1862, the late Mr. James Easton, who held the view that no satisfactory supply of water for fire extinction with constant high pressure could be secured in connection with the ordinary domestic supply, proposed to lay down a completely new set of mains to be used exclusively for fire purposes, but the cost would have been enormous. His estimate was £72,000 per square mile, and his proposal only extended to forty square miles of the metropolis. This area alone would have involved an annual cost for interest and working expenses of £150,000. A somewhat similar proposal, but with the addition that the water was to be taken from the chalk formation at about 15 or 20 miles from the center of London, instead of from the water companies' mains, as was proposed by Mr. Easton, and that the supply was to be used for potable and culinary purposes after being pumped to the greatest attainable elevation, in order that it might have sufficient pressure for fire extinction purposes, was put forward by the Metropolitan Board of Works, on the advice of Sir J. Bazalgette, Sir F. Bramwell, and Mr. Edward Easton, in 1877. It was estimated that the introduction of this system of hydrants would have resulted in an annual saving of £60,000 in the existing expenses of the fire brigade. This scheme, involving a dual supply to every house, was taken to Parliament, but was withdrawn; and, in their annual report of 1878, the Board said that they "came to the conclusion, in view of the disfavor with which the scheme appeared to be regarded by most of the local authorities of the metropolis and others, not to bring it before Parliament again in the following session." Looked at purely from a fire extinction point of view, there is one great objection to all the proposals that have been hitherto made, viz., that owing to the great variations of level in the metropolis, there would, in many localities, be insufficient pressure, while in others the pressure would be excessive.

In any water supply for fire purposes, it is certainly desirable that the pressure, in addition to being sufficient, should also be moderately uniform in the hose, whatever may be the elevation of the locality. This uniformity is practically obtained at present by the use of fire engines, but with the great drawback that the power requisite for giving the pressure is not available on the instant that the occasion for its use is discovered. The diagram B on the wall illustrates among other things the result of the vigorous efforts made by the fire brigade to reduce this

evil to a minimum. It shows that since the year 1870, when Captain Shaw first began to publish the distances traveled by his engines—the distances run have increased from 11 miles to 34¼ miles (in 1882) per fire. The number of journeys made has increased from 8,000 to 29,000, and the total distances run from 22,000 miles to 66,000 miles in the year.

According to the evidence given before Sir H. Selwyn Ibbetson's Committee in 1877, the fire engines were then only used for pumping at about one-fifth of the fires. If that was still the case in 1882, then it follows that for each time the engines were used for pumping upon a fire they must have run, on an average, 172 miles.

When it is considered under what unfavorable conditions, and how uselessly the journeys are often made, some idea may be formed of the superiority of a system of hydrants where the power, as well as the water, is always on the spot ready for instant application. The same diagram illustrates also another feature of the fire brigade service, viz., the growth of its cost from the commencement of the old fire engine establishment in 1833. It will be seen that the growth has been, and is, very rapid as compared with the growth of the population. In the first year of the Metropolitan Board of Works' administration of it the cost of the brigade was under £41,000; in 1882 it was £106,552, or an increase in the period of sixteen years of 160 per cent., while the population increased only 28 per cent., and the number of fires 44 per cent.; and in the year 1883, the cost had further increased to over £115,000. It must not be supposed for a moment that this increase is to be regarded as unnecessary under existing conditions. The cost of the London Fire Brigade is, thanks to Captain Shaw's admirable organization, still small, as compared with some other unhydranted cities. In New York, as already stated, the cost is very much greater for less than a third the population and area. There the average annual cost for the three years, 1880–3, was over £288,000, and it appears to be growing almost as rapidly as that of London, though, on the other hand, the population there is growing more rapidly. Paris, also, another practically unhydranted city, with half the population, spends proportionately more than London for fire extinction.

The question of the cost of fire extinction again, is not the sole consideration; behind that there is the question of fire loss, or the destruction of property by fire, and the loss of life. Putting aside the last and highest question as being one not altogether dependent upon the extinguishing service, I propose now to direct attention to the question of fire losses as affected by the absence or presence of efficient hydrant services.

In describing the hydranted cities I have already given the fire losses in four of them, viz., Glasgow, Manchester, Dublin and Birmingham, in accordance with the published estimates, and I have shown that the losses are—in Glasgow, £215; in Manchester, £234; in Dublin, £125, and in Birmingham £26 11s. per 1,000 of the population. In the case of New York the losses are published in detail, and amount to about £710 per 1,000 of the population, as compared with £588, the loss in the metropolis as estimated by myself.

The Table A has been prepared in accordance with the facts I have stated; but in order to give the figures a practical bearing in the case of the metropolis, I have added two columns which give the costs and losses of a place having the population of London, at the same rates as each of the places considered. It will be seen that the annual cost of extinction by hydrants, if it were at the same rate as Liverpool, Glasgow, Manchester and Birmingham, would be from £30,000 to £40,000; and at the same rate as Dublin, £50,000; while, if it were at the same rate as New York, the cost would be £886,000, instead of £99,880, the average annual cost in London in the years 1880–2.

The diagram H (shown on the wall) has been prepared from Captain Shaw's table, already referred to, and it seems to place the value of efficient hydranting in a very striking light. From the table referred to have been plotted the figures, giving the cost of the fire brigades in a number of important towns at the date of the compilation of the table (in 1877). The cost in the hydranted cities, viz., Glasgow, Liverpool, Manchester and Dublin has been shown in red. The blue line shows the cost in

TABLE A.—ANNUAL COST OF FIRE EXTINCTION, AND ANNUAL AMOUNT OF FIRE LOSSES, IN SOME HYDRANTED AND UNHYDRANTED CITIES.

Average of Three Years, 1880, 1881, 1882.

	Population, 1881.	Area, Square Miles.	Cost of Fire Brigade.	Cost of Fire Brigade per 1,000 Inhabitants.	Cost of Fire Brigade of Metropolis at same rate.	Loss.—Property destroyed by Fire.	Loss. — Property destroyed by Fire per 1,000 Inhabitants.	Loss of Property in Metropolis at same rate.
*** HYDRANTED.**								
			£	£ s.	£	£	£ s.	£
Liverpool	548,649	8.28	5,325	9 14	37,000	—	—	—
Glasgow	510,816	9.55	5,266	10 6	39,290	110,000	215 7	821,542
Manchester	341,508	6.7	3,547	10 8	39,670	80,180	234 16	895,644
†Dublin	249,602	6.0	3,286	13 3	50,200	31,144	124 16	476,050
Birmingham, 1882-3.	411,689	13.15	3,250	7 18	30,115	10,931	26 11	101,287
*** UNHYDRANTED.**								
London	3,814,571	121	99,880	26 4	99,880	2,242,400	587 19	2,242,400
New York	1,240,000	39	288,190	232 8	886,490	880,000	709 14	2,707,150
‡Paris, 1883-4	1,269,023	39	§86,600	§38 3	145,500	‖431,300	‖192 10	734,300

* The terms "hydranted" and "unhydranted" indicate the presence or absence in each place of a complete system of hydrants which are used for fire extinction without the intervention of fire engines.

† The cost of the Fire Brigade has been reduced from £3,616 in 1880, to £3,053 in 1882.

‡ A large number of fire hydrants have been put down, and some have been used without the intervention of fire engines, but the average pressure is not such as to admit of this being generally done.

§ Average of 1883 and 1884, exclusive of rent and repair of quarters, barracks, &c.

‖ Average of 1880, 1881, and 1882.

a number of American cities. Paris and London, having populations respectively twice and over three-fold as great as New York, are not shown, but from the table, and the remarks upon it it will be gathered that in both those cases the cost would be far above the rates shown by the red color, which has been extended to embrace a place of the size of New York.

In the foregoing remarks I have simply taken population as the basis of comparison between the several places. And, I do not pretend to say that there are not exceptional considerations apart from the question of water supply, such as areas, character and proximity of buildings, habits of people and so on, which would, and no doubt do, materially influence results, but the distinction between the hydranted and unhydranted places is so broad and marked where the places are of such different characters on the one hand as Glasgow, Liverpool, Manchester and Dublin, and on the other hand, as London, New York, Paris and Birmingham, that it must appear to all that the absence or presence of efficient hydranting far outweighs any other consideration.

It now remains for me simply to add that, having for some years devoted much study to the subject, I believe that, notwithstanding all the difficulties, only the chief of which have been adverted to here, there are methods—or perhaps I ought rather to say there is a method—by which such cities as London, New York, and Paris may be efficiently hydranted at a comparatively small cost, and practically with very trifling inconvenience, which method I have already described in papers read at the last meeting of the British Association, and before the Institution of Mechanical Engineers. It is, however, impossible, within the

limits of a single paper, as must be sufficiently obvious, to discuss the whole question; I, therefore, content myself on this occasion by advancing the proposition that efficient hydrants form, as far as our experience goes, the only effective weapon with which fire brigades can successfully cope with fires.

On the Purification of Water by Iron on a Large Scale.

BY W. ANDERSON, M. INST. C. E.

In January, 1883, in a paper on the Antwerp Waterworks, read at the institution of Civil Engineers, I described the application of Professor Bischof's method of filtration, through a mixture of spongy iron and gravel to the purification of the waters of the River Nethe. The eighteen months' additional experience gained has shown that, so far as the purification of the water is concerned, Professor Bischof's process leaves little to be desired, but the working of the system has been costly, and the area of land required, as well as the quantity of iron necessary, has, in the case of the Antwerp water, at any rate, proved very much beyond the inventor's expectations.

The increased demands of the town rendered it necessary to extend the arrangements for purifying the water, and it became my duty to advise the directors of the company on the best means of doing this.

The extension of Professor Bischof's method would have involved so great an outlay, that after trying, unsuccessfully, many experiments on direct filtration through unmixed iron at high rates of flow, I determined to adopt a plan first suggested to me some years ago by our chairman, Sir Frederick Abel, of agitating the water to be purified with iron instead of attempting to filter it. The object in either case was to expose the water as much as possible to an extended surface of iron, consequently, any plan by which the iron could be made to keep itself clean by rubbing against itself continually, would seem to be a more rational way of attaining this object, than of trusting to a partial filtration through a more or less spongy material.

The obstacle to trying Sir Frederick Abel's method at a much earlier date, was the belief entertained by Professor Bischof that a contact of about 45 minutes was necessary to ensure complete purification, and any such time would be fatal to mechanical means of performing the work. The late Professor Way and Mr. Ogston, it is true, had shown that with very finely divided iron the effect was much more rapid, but there was still a doubt about its permanence.

In the autumn of last year, a revolving cylinder, 4 ft. 6 in. in diameter, and 5 ft. 6 in. long, was adapted to try Sir Frederick Abel's system. It was fitted with inlet and outlet pipes, and with shelves or ledges for scooping up the iron, raising it to the top of the cylinder, and then letting it fall through the water.

At first I began to run water through at 12 gallons per minute, which gave a contact of about 45 minutes, but I found that at this rate the water was very heavily charged with iron; I gradually increased the quantity to 30 gallons per minute, and then found that 1.20 grains of iron were dissolved per gallon, or about twelve times more than experience at Antwerp showed to be necessary. The flow was increased to 60 gallons, and even then 0.9 grains per gallon were dissolved.

The experiment looked so hopeful that I fitted much larger pipes to the apparatus, and having made some other dispositions connected with maintaining a uniform distribution of iron in the cylinder, and preventing it being washed away by the comparatively rapid current that would be possible, I sent the "Revolver," as it came to be called to Antwerp, where it was put to work at the end of last February, and has continued to operate ever since.

The head available for forcing the water through the "Revolver" is, at Antwerp, limited to 5 feet, but by fitting very large pipes I have managed to get 166 gallons per minute through; this gives a contact of about 3½ minutes, and is so amply sufficient that I feel sure that, even for the waters of the Nethe, much less time will be adequate.

The charge of iron is about 500 lbs., and the quantity taken up by the water, including impurities and very fine iron washed away, during a run of thirty-three days was 0.176 grains per gallon.

By making suitable arrangements, and choosing a favorable time with respect to the demands of the town, we were

able to obtain samples of water that had been purified by the "Revolver" only, and after proper exposure to the air, followed by filtration through one of the large sand filters, the result obtained has been that the color was very little different from distilled water, the free ammonia was reduced from 0.032 grains per gallon to 0.001, and the albumenoid ammonia from 0.013 grains to 0.0045.

The "Revolver" turns at the rate of about $\frac{1}{3}$ revolution per minute, and requires scarcely appreciable power. The area occupied by apparatus for dealing with 2,000,000 gallons per day is 29 feet by 24 feet, and it can be introduced into any existing system of filters, for by enlarging the inlet and outlet pipes to a suitable diameter, a head of some 12 inches will suffice to pass the water through.

It can easily be arranged so as to be used or not, as the state of the water to be purified may warrant, and the consumption of iron being only about 20 lbs. per million gallons is quite an insignificant expense. It will be found to remove all color from water whether caused by peat or clay, and will facilitate the action of sand filters by the peculiar curdling effect the iron has on the impurities.

During the experiments made at Erith, it was noticed that considerable quantities of gas collected in the upper part of the "Revolver." On collecting this gas it was found to extinguish a lighted taper instantly, and on analysis was found to contain only 8 per cent. of oxygen.

It was observed from the first that the animal and vegetable life which was so abundant and troublesome in the natural waters of the Nethe, lying over the spongy iron filters, had quite disappeared in the water, otherwise in exactly the same circumstances lying over the sand filters, and I always supposed that this was due chiefly to mechanical filtration through the spongy iron having separated all the germs, spores and seeds which come to life above it. But, during the recent hot weather, it has been found that the water from the "Revolver," though it contains all the impurities of the natural water, has been modified by the action of iron to such an extent that neither animal nor vegetable life is apparent over the sand filters. Without presuming to draw very wide inferences from this fact with reference to the action of iron upon organisms connected with disease it may, at least, be pointed out that the absence of visible life in water treated by iron on a large scale confirms, in a great measure, the experiments of Dr. Frankland, Dr. Voelcker, Mr. Hatton, Professor Bischof, and others. It is due to the last-named gentlemen to state that to his persistent advocacy the introduction of iron as a purifier is mainly due. It must be borne in mind that the system does not depend on filtration only, but, first, on a process of exposure to iron, which decomposes the organic matter, and kills living organisms; and, secondly, on simple filtration, which merely separates the noxious matters which had been previously attacked by the iron. The waters of the Nethe are exceptionally bad, and heavily charged with impurities, so that the test both of Professor Bischof's and Sir Frederick Abel's systems has been very severe.

THE Russian review, *Russkaya Starina* and the *Journal* of the Russian Chemical and Physical Society have lately devoted some attention to the first steam engine that was made in the Russian Empire, in 1763, at the ironworks of Barnaoul, in Western Siberia, by a mining engineer, Polzunoff. It appears from M. Woyeikoff's description of this steam engine, the model of which, *Nature* says, exists still at Barnaoul—both reviews have figured it on plates—that Polzunoff's engine was a reproduction of the "fire-engine" of Newcomen, with some original improvements. Thus, it has two cylinders, instead of one, and, instead of the beam, Polzunoff made use of a wheel which received the chains of the pistons, and transmitted the circular movement, transformed again into a rectilinear one, to a pair of bellows, used for blowing air into a high furnace. The distribution of vapor was automatic, as in Newcomen's engine, but with several improvements. The engine, which had cylinders 9 ft. long and 9 in. in diameter, worked during two months from May 20th, 1766, and 3100 cwt. of silver ore, yielding 5 cwt. of silver, were melted with its help. But Pulzunoff did not see his engine at work, as he died from consumption four days before. He was a remarkable man for his time. In his theoretical remarks about "Air, Water, and Vapor," he notices also that physicists are not agreed as to the origin of heat, some of them seeing in it a much-divided, fine moving matter, while others "see the origin of heat in friction and in the vibratory motion of the particles inaccessible to our senses, of which the bodies are constituted." He obviously quotes here the words of Lomonosoff, who stated in these words the mechanical origin of heat in his little-known memoir, written as an instruction to Tchitchagoff's Polar Expedition.

SIZE AND INCLINATION OF SEWERS.

By ALFRED EDWARD WHITE, Assoc. M. Inst. C. E.

From Selected Papers of the Institution of Civil Engineers.

THERE is no doubt that each of the two systems of sewerage, the separate and the combined, possesses certain advantages and certain disadvantages, as compared with the other; there being some conditions under which the former system may be adopted with the greater benefit, and other conditions under which the latter is the more applicable. An advantage of some importance, however, which the separate system possesses over the combined system, is that of allowing of the use of sewers of a smaller size.

As a rule, the smaller a sewer (within certain limits) the better, provided it is large enough to deliver the maximum quantity required to be disposed of; and the smaller the excess of the maximum flow over the ordinary flow, the more efficient may the sewer be made for the conveyance of the ordinary flow. A sewer constructed to receive the whole of the surface water in addition to the sewage, will not, with the dry-weather flow consisting of sewage only, work as efficiently as a smaller sewer, constructed to convey the sewage with only a limited quantity of surface water. The larger sewer is so much in excess of the requirements of the dry-weather flow, that it will not under ordinary circumstances be self-cleansing to the same extent as the smaller sewer, while the smaller may also be more efficiently flushed with a moderate supply of water.

It probably is necessary in almost all cases (in order to avoid an unreasonably complicated arrangement of branch drains) to admit the water from back roofs and back yards to the sewers, even where there are separate drains for surface water; but the greater the quantity so admitted the more it will tend to neutralize the advantage above referred to.

To determine the volume of the dry-weather flow in any sewer is a comparatively simple matter, if sewage only be admitted to it, as such volume may be considered equal to the amount of the water-supply; which amount is usually known with sufficient accuracy, and for an average town may be taken at 25 gallons per head per day. In making provision for the maximum dry-weather flow of sewage, it is usual to assume that one half the daily quantity is discharged in from six to eight hours; if, therefore, the daily quantity be assumed at 25 gallons per head, the maximum flow will be at the rate of $12\frac{1}{2}$ gallons per head in (say) six hours, or about 2 gallons per head per hour.

The amount of rainfall, which it is necessary to provide for in the sewers, is a much more difficult matter to determine, and one which seems to be often under-estimated. In the first place it is necessary to estimate the amount which the sewers should be capable of receiving above storm-overflows; and in the second place the amount which they should deliver below such overflows. To prepare for the heaviest rains in this country is out of the question, considering the excessive falls which occasionally take place. The rate of rainfall to be provided for above the overflows should be determined with due regard to the degree of risk of such rate being exceeded, and to the amount of inconvenience or damage which would be caused in the event of its being exceeded; but to incur a great expense in constructing large sewers, merely to avoid the probability of their overflowing and causing a small amount of damage, once or twice in a generation, would be unreasonable. Such expense, however, might be justified where the probability of overflow, and also the damage likely to ensue, were great. With regard to the sewers below storm-overflows, their capacity should be sufficient to avoid overflows of such frequency and amount, as would seriously pollute the watercourses or rivers receiving the overflows.

Under the separate system the only rain which should find its way to the

sewers is that falling upon back roofs and back yards, and the quantity may be estimated from the area of such roofs and yards, together with the maximum rate at which rain falls. The above area may be taken at an average of 500 square feet for a house occupied by five persons, or 100 square feet per head of the population, and it may be assumed that the entire rainfall upon such area is discharged into the sewers.

The published rainfall tables, of the description required to determine the maximum rate at which there is a probability of rain falling, are of a very meager character. Observations of rainfall are not usually taken at shorter intervals than twenty-four hours, and the duration and amount of most heavy rains consequently are not recorded. In the volumes of "British Rainfall,"* there are, however, tables giving all the exceptionally heavy falls reported by observers in various parts of the United Kingdom, and by these tables some valuable information on the subject is given. Taking the records of the three years, 1880, 1881 and 1882; there are reported fifty-seven falls at a rate of over 1 inch per hour, forty-two over 1¼ inch, thirty over 1½ inch, eighteen over 2 inches, six over 3 inches, and two over 5 inches per hour. The heaviest fall reported was at the rate of 5.80 inches per hour, and it continued for thirty minutes. Regarding these records, the impracticability of providing for the heaviest falls is obvious; it seems to the author, however that a fall at the rate of 1¼ inch per hour should in average cases be provided for, in sewers which are not relieved by storm-overflows; and for the purpose of future calculations it is assumed that such sewers should be capable of receiving a fall of this amount. It should be stated that many of the above-mentioned forty-two falls, which exceeded 1¼ inch per hour, were of such short duration that they would not cause sewers, capable of discharging this amount, to overflow, as the capacity of sewers, independent of their discharging power, is considerable.

The available statistics, of the character necessary to determine the amount of rainfall which it is desirable to provide for in sewers below storm-overflows, are, for the purpose required, of a more satisfactory nature than those above referred to. "British Rainfall" for the year 1880 contains a very useful table, contributed by Mr. Baldwin Latham, M. Inst. C. E., prepared from the records of a self-recording rain-gauge at Croydon; such table giving the quantity, duration, and rate per twenty-fours hours, of all falls of rain of any importance, from March, 1879, to April, 1881. Some similar information is afforded by the records of a self-recording rain-gauge at Camden Square, London, which have very kindly been placed at the disposal of the author by Mr. Symons. As these records have not before been tabulated, a table prepared from them, giving particulars of the important falls of 1881 and 1882, is appended to this paper.

Table 1, which is an abstract from the above-mentioned tables, shows the number of times certain rates of rainfall were exceeded in two years; also the aggregate duration of the falls exceeding these rates.

TABLE I.

	Rate of fall in fractions of an inch per hour.	Number of times rate was exceeded in two years.	Aggregate duration of excessive falls in hours.
Croydon Records	¼	38	20¼
	⅓	78	45
	½	108	73
	1/12	154	115½
Camden Square Records	¼	59	11½
	⅓	99	35¾
	½	136	71¾
	1/12	202	119

From this table may be obtained, approximately, the number of times that storm-overflows would come into action with sewers capable of discharging various amounts of rain, and also the aggregate duration of the overflows. As, however, a number of the falls included were of very short duration, and in many cases would not be simultaneous over the whole drainage area, it may be assumed that some of them would not cause overflows, and that the duration of the overflows caused by others would be reduced; and to compensate for this a deduction of (say) 20 per cent. should be

* "On the distribution of rain over the British Isles." Compiled by G. J. Symons, F. R. S.

made from the figures in Table 1. Now, taking a sewer capable of discharging a rainfall of $\frac{1}{8}$ inch per hour, and making the required deduction, the number of overflows during two years, according to the Croydon records, would be eighty-six, and according to the Camden Square records one hundred and nine, and their aggregate duration, in each case, about fifty-eight hours; or during one year the number of overflows would be forty-three and fifty-four and a-half respectively, and their duration, in each case, about twenty-nine hours. Overflows to this extent in most cases, and probably to a considerably greater extent in many cases, would be admissible, and for the purpose of future calculations it is therefore assumed that sewers below storm-overflows should be capable of discharging $\frac{1}{8}$ inch of rainfall per hour.

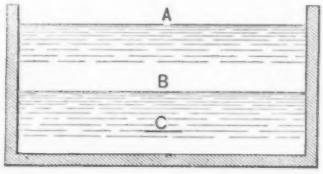
It is of interest to notice that of the rainfalls at Croydon and Camden Square, during the above period, none amounted to the maximum quantity which would be received by sewers capable of discharging $1\frac{1}{4}$ inch per hour. Eight falls were in excess of one-half the capacity of such sewers, forty six of one-quarter, and one hundred and sixty-eight in excess of one-eighth their capacity. The heaviest fall, which was at Camden Square, continued for ten minutes at the rate of 1.68 inch per hour; this, however, taking into consideration the shortness of its duration, was about 12 per cent. below that which sewers capable of discharging $1\frac{1}{4}$ inch per hour would receive. The fall second in importance was at Croydon, and continued for ten minutes at the rate of 1.34 inch per hour, this being about 30 per cent. below the amount the sewers would receive.

Upon the area before mentioned as that which may be assumed to be covered, per head of the population, by back roofs and yards, viz., 100 square feet, a rainfall of $1\frac{1}{4}$ inch would produce 65 gallons; and as the maximum volume of the sewage proper, in average cases, as already determined, is about 2 gallons per head per hour, a total of 67 gallons per hour should be provided for in sewers which are not relieved by storm-overflows. With regard to sewers below storm-overflows, the volume to be provided for, per head per hour, according to the foregoing conclusions, is a rainfall of $\frac{1}{8}$ inch on 100 superficial feet, or $6\frac{1}{2}$ gallons, and 2 gallons of sewage, making $8\frac{1}{2}$ gallons.

Sewers should, where possible, be constructed with such inclinations as will render them self-cleansing with the ordinary flow of sewage; and where this is impracticable, the inclination should at least be sufficient to give a self-cleansing velocity with the assistance of flushing.

As to the velocity necessary for self-cleansing purposes, authorities differ somewhat. It seems to be usually considered that small sewers require a greater mean velocity of sewage flow than large sewers, but the grounds upon which this assumption is based do not seem very clear. The bottom velocity is that upon which the self-cleansing properties depend; but how is this velocity to be determined? The size, form, gradient, and depth of flow of a sewer being given, there are several reliable formulas for calculating the mean velocity, but not so the bottom velocity. One authority states the bottom, mean and surface velocities to be nearly as 3, 4 and 5, and others express the ratio by figures nearly corresponding with these. It appears to be assumed that these proportions apply under all circumstances; but that this is a mistaken assumption, the author would submit, may be proved as follows:

If a trough be taken, as shown by the annexed diagram, in which the water is up to A, then, according to the above rule, if the velocity of flow at A be represented by 5, that at B, half-way down, will be about 4, and at the bottom 3, while the velocity at C, mid way between



the bottom and B, will be about $3\frac{1}{2}$. Now if the water be only up to B—that is to say, of half the depth before assumed—and the inclination be increased so that the mean velocity is the same as before, then the velocity at C, it being about the mean, will be 4. Thus in the former case

the velocity at C, which was 3½, was less than in the latter, the mean velocity in each case being the same. How then will the bottom velocities in the two cases correspond? The velocity of the bottom water is affected by three forces: I. Its own gravity, due to the inclination of the trough. 2. The velocity of the water directly above. 3. Its friction upon the bottom of the trough. The first force, that of gravity, is greater in the latter case, or with the shallow flow, as the inclination is greater; the second force, that of the water above, is also greater in the latter case; for, taking any point above the bottom, as, for instance, the point C, the velocity at that point is greater in the shallow flow. The third force, that of friction, upon the bottom of the trough, is equal in each case. Both the force of gravity, and the greater velocity of the water above, tend to give the bottom-water a greater velocity with the shallow flow, and it is therefore evident that the difference between the mean and the bottom velocity is greater with a deep flow of sewage than with a shallow flow, or, under ordinary circumstances, with a large sewer than with a small one. It would therefore appear that the mean velocity necessary to render sewers self-cleansing is greater with a deep flow than with a shallow flow.

It may be assumed that 150 feet per minute is an ample self-cleansing velocity for ordinary sewers when running half-full or thereabouts, and 135 feet per minute is probably quite sufficient for a shallow flow, such as that discharged in dry weather, provided the sewage be sufficiently deep to float or submerge the solid matters contained in it.

The inclinations necessary to produce a velocity of 150 feet per minute in circular sewers of various sizes, flowing half-full, or full, and in egg-shaped sewers flowing two-thirds their vertical height, are shown in Table 2; also the population which such sewers, when running full, would be capable of serving at 67 gallons per head per hour above storm-overflows, and 8½ gallons below storm-overflows.

Sewers should be constructed to flatter inclinations than the above, and these inclinations are only admissible where flushing power is provided.

TABLE II.

Size of Sewer.	Inclination to produce velocity of 150 feet pr. minute.	Population served by sewers above storm overflows.	Population served by sewers below storm-overflows.
Ft. In. Ft. In.			
0 6×0 6	1 in 174	165	1,297
0 9×0 9	" 261	370	2,919
1 0×1 0	" 349	658	5,189
1 3×1 3	" 436	1,028	8,107
1 6×1 6	" 524	1,481	11,675
2 3×1 6	" 661	2,080	16,390
2 6×1 8	" 734	2,567	20,235
2 9×1 10	" 808	3,106	24,485
3 0×2 0	" 882	3,697	29,140
3 3×2 2	" 955	4,340	34,200

In the preparation of the foregoing and following tables, the formulas used are those of Eytelwein, viz.:

$$V = 5604\sqrt{R\,S}.$$

$$S = \frac{V^2}{R\,(5604)^2}.$$

Where V = velocity in feet per minute.
S = sine of inclination.
R = hydraulic radius.

To ascertain the gradients required for self-cleansing with the dry-weather flow, it is necessary to determine the amount of such flow as compared with the capacity of the sewers. According to the figures already given, the maximum quantity to be provided for in sewers above storm-overflows is 33½ times, and in sewers below storm-overflows 4½ times, the maximum dry-weather flow. The difference, however, between the dry-weather flow and the capacity of the sewers would often be considerably greater than this, as sewers are of necessity somewhat larger than necessary for the maximum flow, through certain portions of their length, especially on approaching dead ends. To allow the required margin, let it be assumed that the capacity of sewers above storm-overflows is 45 times, and below storm-overflows 5 times, the maximum dry-weather flow. Working upon these proportions, the inclinations required above storm-overflows in sewers of various sizes, to produce a velocity of 135 feet per minute with the dry-weather flow, are shown

by Table 3; also the depth of the dry-weather flow, the assumed population contributing to it, the velocity when running full, and the population which the sewers, when running full, would be capable of serving, at 67 gallons per head per hour.

TABLE 3.

Size of Sewer.	Inclination to produce velocity of 125 ft. per minute, with maximum dry-weather flow.	Depth of dry-weather flow, or of flow equal to one forty-fifth the capacity of sewer.	Population contributing to dry weather flow.	Velocity when running full, in feet per minute.	Population served by sewer when running full at 67 gallons per head per hour.
Ft. Ins. Ft. Ins.		Inch.			
0 6 × 0 6	1 in 50	0.56	230	280	308
0 9 × 0 9	" 75	0.83	514	"	691
1 0 × 1 0	" 100	1.11	915	"	1,229
1 3 × 1 3	" 125	1.39	1,428	"	1,919
1 6 × 1 6	" 150	1.67	2,057	"	2,764
2 3 × 1 6	" 214	2.63	2,708	252	3,638
2 6 × 1 8	" 238	2.92	3,343	"	4,491
2 9 × 1 10	" 262	3.21	4,046	"	5,435
3 0 × 2 0	" 286	3.50	4,816	"	6,468
3 3 × 2 2	" 310	3.79	5,650	"	7,590

Table 4 gives particulars, similar to those in the preceding Table, with reference to sewers below storm-overflows, the maximum flow being taken at $8\frac{1}{2}$ gallons per head per hour.

TABLE 4.

Size of Sewer.	Inclination to produce velocity of 135 ft. per minute, with maximum dry-weather flow.	Depth of dry-weather flow, or of flow equal to one-fifth the capacity of sewer.	Population contributing to dry-weather flow.	Velocity when running full in feet per minute.	Population served by sewer when running full at $8\frac{1}{2}$ gallons per head per hour.
Ft. Ins. Ft. Ins.		Inch.			
0 6 × 0 6	1 in 145	1.76	1,213	165	1,427
0 9 × 0 9	" 217	2.64	2,729	"	3,211
1 0 × 1 0	" 289	3.52	4,852	"	5,708
1 3 × 1 3	" 361	4 40	7,581	"	8,919
1 6 × 1 6	" 434	5.28	10,917	"	12,843
2 3 × 1 6	" 525	8.79	15,577	161	18,326
2 6 × 1 8	" 583	9.77	19,231	"	22,625
2 9 × 1 10	" 642	10.75	23,270	"	27,377
3 0 × 2 0	" 700	11.72	27,693	"	32,580
3 3 × 2 2	" 758	12.70	32,502	"	38,237

The difference shown in Tables 3 and 4 between the population contributing to the dry-weather flow, and the population which the sewers are capable of serving, represents the margin allowed in determining the amount of the dry-weather flow, as compared with the maximum flow, as previously explained. Should the population contributing to the dry-weather flow be less than that stated, in which case the volume of sewage would also be less, an increased inclination would be required to give the self-cleansing velocity.

The size of sewer for inclinations other than those in the tables may easily be calculated from those given, the discharge being in proportion to the square

root of the sine of the inclination. The sine, however, for a given population and given inclination, may vary considerably, according to the local conditions affecting the volume of sewage per head to be disposed of.

With sewers on the combined system, the maximum amount of water to be dealt with, in proportion to the population, would probably be, in an average case, three times that provided for in the tables; and the population served by a sewer of a given size would consequently be proportionately less.

ON THE CONSUMPTION OF FUEL IN LOCOMOTIVES.*

By M. GEORGES MARIE, Engineer of the Paris and Lyons Railway.

From "The Engineer."

During the past twenty years a great advance has been made in regard to economy of fuel in steam engines. In marine engines remarkable results have followed from the general use of compound cylinders and surface condensers; for whereas their consumption was formerly from 3½ lbs. to 4½ lbs. per indicated horse-power per hour, it has now been reduced to about 2 lbs., and sometimes even less.† Equally good results are obtained with Corliss engines. This progress in economy of fuel has led to the endeavor to effect a corresponding reduction in locomotives. But, before the ordinary build of locomotives so long in vogue is abandoned, their exact consumption ought to be ascertained. Generally it is measured in pounds per mile; but that mode is not a convenient one for comparison, because it takes no account of gradients, weight of train, speed, and train resistance, all of which are so variable that the bare statement of consumption per mile is of scarcely any value. The only proper way of reckoning the consumption, so as to admit of comparison under different circumstances, is in pounds per horse-power per hour; and this is accordingly the new methods described in the present paper, as applied to locomotives under ordinary working conditions. There is a general impression that locomotives consume as much as from 4½ lbs. to 5½ lbs. of fuel per horse-power per hour. With a view to dispel this very prevalent error, the author can quote experiments made by him during the last few years, which show an average consumption in good locomotives of 3.35 lbs., when the horse-power is measured by the work done at the circumference of the driving wheels, and of 2.91 lbs. when it is measured by the indicator diagrams; the fuel being of good quality and the firing done with care. Comparing this with the marine engine consumption of 2 lbs. per indicated horse-power, it is seen that locomotives are much more economical than is usually supposed, considering that they work non-condensing while marine engines enjoy the great advantage of condensation. The author's first experiments on this subject, made in 1877 on the line between Rive-de-Gier and St. Etienne in the department of the Loire, gave a consumption of 2.90 lbs. to 3.24 lbs. per indicated horse-power per hour;* other experiments confirming this consumption were also made on a longer length between Alais and Langeac on the Nimes and Clermont line. These results, which were widely criticised, led M. Hirsch, Professor of Steam and Engineering at the Ecole des Ponts et Chaussées, to request that the experiments might be repeated in his presence. Fresh trials, which may be considered official, were accordingly made with him on 18th, 20th and 21st of July, 1882, on the Mont Cenis line between St. Jean de Maurienne and Modane, with the ordinary trains. The average consumption was again found to be 2.90 lbs. per indicated horse-power per hour. In these experiments neither indicator nor dynamometer of

* Read before Institution of Civil Engineers.

† See Paper by Mr. F. C. Marshall, Proceedings 881, p. 452.

* See "Revue des Chemins de fer," July 1881, p. 17.

any kind was used, such delicate instruments being liable to give rise to errors. Indicators especially occasion considerable errors through the oscillations of the piston-rod and spring, and in general give accurate results only from stationary engines working at slow speeds. The following are the particulars of the three days' trials, which it is hoped will successfully clear the locomotive from the imputation of wastefulness in consumption of fuel.

Choice of Line.—For experiments of this kind the writer generally chooses a steep rising gradient, because the work performed by the engine can then be easily and accurately calculated. It then consists of two portions: first, the work due to the train resistance on a level; and secondly, that due to gravity on the incline. On a steep rising gradient this latter portion becomes much the more important, while it can always be determined with accuracy, being the product of the total weight of train and engine, multiplied by the difference in level between the two ends of the incline; whereas the calculation of train resistance on a level is always subject to slight errors, arising from variations in the circumstances of wind and weather. Hence the steeper the incline up which the engine takes the train, the greater is the accuracy with which work done can be calculated. In this way the engine duty can practically be determined without the use of either indicator or dynamometer of any kind. The portion of line selected for the trials has the length of $27\frac{1}{8}$ miles between St. Jean de Maurienne and Modane stations on the Mont Cenis line; the gradients are 1 in 100 to 1 in 35, rising towards Modane, which is 1709ft. above the lower station; the average gradient is 1 in $53\frac{1}{2}$.

Choice of Train.—The train chosen was a passenger train starting from St. Jean de Maurienne at 12.21 noon, stopping only once on the way, at St. Michel, for three minutes, and reaching Modane at 1.25 P. M.; the average speed being accordingly 17.40 miles per hour. The engine, built from the designs of the writer's father, the late Ernest Marié, had eight wheels coupled, and its principal dimensions were as follows:

Cylinders	Diameter.....	$21\frac{1}{4}$ in.
	Stroke.....	26 in.
Wheels, diameter.....		4 ft. $1\frac{5}{8}$ in.
Heating surface	Fire-box.. 104.52	2149.70 sq. ft.
	Tubes.....2045.18	
Fire-grate area.....		22.39 sq. ft.
Boiler pressure.....		128 lbs. per sq. in.

The weight of the train, ascertained with the greatest care, was 163.58 tons, the particulars of which are given in the tabular summary appended; engine, tender and carriages were all weighed accurately on weighing machines.

Calculation of work done.—If calculated at the circumference of the driving wheels, not in the cylinders, the work done is exclusive of the engine friction, and is given by the following formula: Work done $= W \times l \times r + W \times h$. Here W = total weight of train, including engine and tender = 163.58 tons = 366,419 lbs.; l = distance run = 17.334 miles = 91,536 ft.; r = coefficient of resistance = $\frac{1}{232.5}$ in the present case, or $9\frac{5}{8}$ lbs. per ton; h = height of train's ascent = 1,709ft. The choice of the coefficient $\frac{1}{232.5}$ will be explained further on. Substituting the foregoing values—

$$\text{Work done} = 366{,}400 \times \left(91{,}536 \times \frac{1}{232.5} + 1709\right)$$
$$= 366{,}400 \times (394 + 1709)$$
$$= 770{,}600{,}000 \text{ foot pound}.$$

Of this work the portion due to the resistance on a level amounts to $\frac{394}{394+1709}$ or barely one-fifth, while gravity absorbs the remaining four-fifths. Hence an error of as much as 10 per cent. in the coefficient of resistance occasions only 2 per cent. error in the calculation of the work; while even 20 per cent. error in the coefficient causes only 4 per cent. error in the result. Although, therefore, the coefficient here taken of $\frac{1}{232.5}$ may be open to criticism, it is clear that it may be considerably modified without sensibly affecting the calculation of the work done. This constitutes the principle on which the author's trials have been based; whereby he has been enabled to arrive at an accurate deter-

mination of the work done, without the use of either indicator or dynamometer of any kind. The only objection to the method is that it applies only to moderate speeds, inasmuch as high speeds would be dangerous on the curves of a mountain line.

Consumption of fuel.—To ascertain correctly the consumption of fuel the author employed a different method from that ordinarily followed in locomotive trials. The general plan is, after lighting the fire and getting up steam, to note the pressure shown by the gauge, and the height of the water level, and to estimate the quantity of coal then on the grate. The trial is then made, and is so arranged as to end with the same pressure and water-level as at starting, and the coal remaining on the grate is again estimated. The correct consumption is arrived at by measuring the quantity consumed on the journey, adding what was on the grate at starting, and subtracting what remains at the end. Unfortunately it is impossible to determine correctly the quantity of burning fuel on the grate; and in consequence the calculated consumption almost always involves a serious error. This is one cause of the discrepancies met with in statements of fuel consumption. In the author's trials the above source of error has been completely avoided by the following mode of procedure. The engine tried had already made one journey that morning, so that it was in steam, with a pressure of 46 lbs. per square inch, before lighting the fire for the experimental trip. The water-level was 5.16in. above the mean line. The fire-grate was cleared of every particle of fuel from the previous journey. The tender was loaded with one ton, or 2,205 lbs., of Anzin patent fuel in bricks, and 119 lbs. of wood was served out for lighting the fire. The wood was included as fuel in reckoning the actual consumption, and was taken as equivalent to not more than 44 lbs. of coal; the total supply of coal would therefore be 2,249 lbs. Steam was quickly got up, and shortly afterwards the engine was coupled to the train in St. Jean de Maurienne station, and proceeded thence up the incline to modane. The trip was made with the engine working in the ordinary way, with 128 lbs. of steam, cut off at 19 per cent. of the stroke. Professor Hirsch, and M. Bazire, of the locomotive department, accompanied the author on the engine. The firing was so managed as to have no coal at all left on the grate on reaching Modane. The steam pressure was then found to be 20 lbs. per square inch, and the water-level 4.49in. below the mean; the datum level in the locomotives of the Lyons Railway being not the actual low-water line, but a mean level below which the water may fall without danger. The water-gauge was of course observed while the engine was on the level portion of the line in the station, the line running level through every station on this railway. The coal remaining in the tender weighed 1,133 lbs., which would show a consumption of 2,249−1,133=1,116 lbs., if the boiler had been in exactly the same state after the trip as before; but no skill could succeed in securing the same steam pressure and the same water level as on lighting the fire. A slight correction has therefore to be made in the coal consumption, to allow for the difference in quantity of heat contained in the boiler before and after the trip.

Correction for difference of heat in boiler.—Calculating first the quantity of heat contained in the boiler on lighting the fire, and secondly, the heat remaining in it after the trip, the difference converted into pounds of coal will be the correction to be made in the weighed consumption of 1,116 lbs., to give the true consumption. Firstly, at the time of lighting the fire, when the water-gauge stood at 5.16in. above datum, the quantity of water in the boiler would be 1,571 gallons, or 251 cubic feet, as ascertained from the dimensions given in the tabular summary appended. The temperature corresponding with the steam pressure of 46 lbs. is 293 deg. Fah. The weight of water, therefore, allowing for its expansion, would be 14 506 lbs.; and this, at the temperature of 293 deg. Fah., would contain 3,436,000 heat units, reckoning from the temperature of the air at the time, which was 59 deg. Fah. The metal of the boiler, weighing about 20 tons, would contain about 1,175,000 heat units. The heat in the steam may be neglected. Hence the total quantity of heat contained in the boiler at the time of lighting the fire, above the air tem-

perature of 50 deg. Fah., would be 4,611,000 units. Secondly, the heat remaining in the boiler after the trip, estimated in the same manner, would amount to 3,143,000 units. The difference, or 1,468,000 units, is therefore the additional heat expended during the trip. As the weight of dry steam generated per pound of coal consumed was found to be 8.08 lbs., and as each pound of steam at the pressure of 128 lbs. per square inch contains 1,169 heat units above this feed-water temperature of 59 deg. Fah., the boiler would produce, in practice, $8.08 \times 1{,}169 = 9{,}445$ heat units per pound of coal. The additional expenditure of 1,468,000 heat units during the trip is therefore equivalent to 155 lbs of coal, which, added to the weighed consumption, gives 1,271 lbs. as the true consumption of coal for the trip.

Consumption of fuel per effective horse-power per hour.—The work done, corresponding with the above consumption of 1,271 lbs. was 770,600,000 foot-pounds. Hence the coal consumption per horse-power per hour was

$$\frac{33{,}000 \times 60 \times 1{,}271}{770{,}600{,}000} = 327 \text{ lbs.},$$

the work being the effective work, *i. e.*, that measured at the circumference of the driving wheels. Throughout the foregoing calculation, the only coefficient open to dispute is that of the train resistance, which has been taken at $\frac{1}{232.5}$; but it has been seen that even a considerable percentage of error in this coefficient would involve no appreciable error in the final result of 3.27 lbs. consumption per effective horse-power per hour. To get at the consumption per indicated horse-power per hour, it is only necessary to deduct the proper allowance for the engine friction; which has been found, in careful experiments made by the writer's father, to absorb at least 12 per cent. of the indicated power, when the engine is in perfect working order. Hence the corresponding consumption per indicated horse-power per hour would be $3.27 \times \frac{100-12}{100} = 2.88$ lbs. as a maximum.

Consumption of water and production of dry steam.— The consumption of water on the trip, from the tender and from the boiler, was measured with the greatest care, allowing for expansion of the water in the boiler. It was found to amount to 11,290 lbs., or 8.88 lbs. per lb. of fuel. Deducting 9 per cent. for priming, the weight of dry steam produced would be 8.08 lbs. per lb. of fuel.

Nature of fuel—Samples carefully analyzed of the Anzin patent fuel, which was used in the trip, showed 6.9 per cent. of ash, and 1 per cent. of moisture. The heating power was found to be 14,600 units per lb. It was ascertained by means of apparatus specially made for the purpose, similar to that used by Ebelman, Fabre, Silbermann and Berthelot, in their experiments on the heating power of fuel. It consists of a glass phial, within which a powdered sample of the fuel, placed in a crucible, is burnt in a current of oxygen; the phial is immersed in a measured quantity of water, and the rise of temperature in the water indicates the heat developed by the combustion of the sample. Cardiff coal was tried in the same way by the author, and gave the same heating power; a direct comparison can therefore be made between the experimental trip and any English trials with Cardiff coal. The Anzin patent fuel is in fact composed of 91 per cent. of slack, of the same quality as Cardiff coal, and 9 per cent. of coal pitch, the heating power of which has been found by the writer to be equal to that of ordinary coal.

Remarks.—During the experiment, the admission of steam to the cylinders was for 19 per cent. of the stroke, the steam in the waste spaces being included. The valve gear was tested by Professor Hirsch himself. The locomotive had not been repaired for a long time. It may be objected that the driver probably looked after the fire much more closely than usual, being stimulated by the presence of the engineers. This may be, but, on the other side, the following circumstances were unfavorable to economy of fuel: (1) During the firing up, the locomotive gave out some heat to the atmosphere as usual; this loss of heat was equivalent to about 29 lbs. of fuel, according to an experiment made for that special purpose. (2) In the last few minutes of the trial, the engine was run-

ning with a very low pressure, which was necessary in order to arrive at Modane without any fuel on the fire-grate; hence the engine was working during these minutes in unfavorable circumstances.

Experiments made the 20th and 21st July, 1882.—The author, with Professor Hirsh, made two other experiments of the same kind as the first: on the 20th July, with patent fuel from the Grand Combe in the Gard coal basin, and on the 21st July, with patent fuel from La Chazotte in the Loire basin. The results were almost exactly the same as before. A tabular summary of the three experiments is appended in which all the figures may be seen at a glance. The experiments were all made with the same driver, the same engine, and the same kind of train. It will be noted that they were made in July, that is to say in the middle of summer. In winter the consumption of fuel is about 10 to 15 per cent higher, on account of the loss of heat to the atmosphere. The author considers that this loss of heat might be diminished if the clothing of the boiler were better—a point which assuredly is susceptible of improvement, especially for cold countries.

Conclusions.—The author has proved that with a good locomotive and a good driver the consumption of fuel and water is as follows:

Consumption of fuel per effective horse-power per hour	3.27 lbs.
Consumption of fuel per indicated horse-power per hour	2.88 lbs.
Ratio of consumption of water to consumption of fuel	8.88
Ratio of dry steam produced to fuel consumed	8.08

Professor Hirsch attributes these satisfactory results to the following causes: (1) The total heating surface of the boiler is very large compared to the grate surface—96 to 1—so that the boiler absorbs the heat of the gases very completely; (2) the cylinders of the locomotive are very large—according to the late M. Marié's system—so that the grade of expansion is high; (3) the locomotive was very well looked after, which is an important point in economy of fuel. The author may also refer to some experiments made by M. Regray, chief engineer of the Eastern Railway of France; they were made with an indicator on a new system, giving diagrams at the highest speeds without the errors of the ordinary indicator. M. Regray, on this system, takes the diagrams at some distance away from the locomotive itself; the indicator is in a special van, with several dynamometers, speed indicators, &c. This van was shown at the Electric Exhibition in Paris, and obtained one of the highest prizes.

M. Regray made a few experiments on consumption of fuel in express engines hauling express trains; the result was 3.01 lbs. per indicated horse power as an average, and 2.48 lbs. as the minimum. This is a very satisfactory verification of the author's result, viz., 2.88 lbs. per indicated horse-power. It is important to notice that these very close results have been arrived at by two methods as different as they could possibly be. The fuel employed in M. Regray's experiments was not patent fuel, but ordinary small coal from Bascoup, in Belgium. These satisfactory results confirm what the author's father always maintained, namely, that locomotive engineers ought to use large heating surfaces and large cylinders; he always built his own locomotives by that rule.

The author has thus endeavored to prove that locomotives are not so imperfect as engineers generally believe, as regards economy of fuel. Assuredly the locomotive is a very simple form of engine; but simplicity is of great importance with the very high piston-speed of locomotives. That speed, however, is very favorable to economy in fuel—contrary to the opinion of some engineers—because it diminishes the leakage of steam and the condensation of steam during admission. A locomotive working with a very slow piston speed is not so economical as with a high speed. Express engines give better results than mountain engines, as is seen by M. Regray's experiments, where the consumption attained the very low figure of 2.48 lbs. per indicated horse-power under the best circumstances.

The author has no intention of implying that locomotives will not be improved—in fact, he proposes to indicate further on the probable directions of improvement; but before abandoning the ordinary system, he thought it would be interesting to make exact experiments,

TABULAR SUMMARY OF EXPERIMENTS.

Items of experiments.	Units.	18th July. Patent fuel Anzin.	20th July. Patent fuel Grand' Combe.	21st July. Patent fuel La Chazotte.
Total distance run by train.	foot	91,536	91,540	91,540
Ratio of resistance on level to weight of train.	ratio	$\frac{1}{232.5}$	$\frac{1}{232.5}$	$\frac{1}{232.5}$
Difference of level of the two stations.	foot	1,709	1,709	1,709
Weight of engine and tender (not loaded)	lbs.	125,076	125,076	125,076
Weight of carriages and vans (not loaded)	"	204,800	225,285	176,212
Weight of the load on engine and tender	"	21,614	24,738	26,422
Weight of passengers and men	"	7,409	5,711	4,785
Weight of goods	"	4,575	4,264	3,149
Total weight of train	"	366,474	385,074	335,614
Before firing the boiler at St. Jean-de-Maurienne. Patent fuel and fagots loaded on tender	lbs.	2,249	2,251	2,249
Before firing the boiler at St. Jean-de-Maurienne. Pressure in boiler (above atmospheric pressure)	lbs. per sq. in.	46.28	21.36	18.23
Before firing the boiler at St. Jean-de-Maurienne. Height of water in boiler (above water-line)	inch	+5.16	+5.24	5.08
After arrival at Modane. Fuel remaining on tender	lbs.	1,133	966	1,158
After arrival at Modane. Pressure in boiler (above atmospheric pressure)	lbs. per sq. in.	19.65	21.36	7.83
After arrival at Modane. Height in water in boiler (above or under water-line)	inch	−4.49	+0.82	−4.73
After arrival at Modane. Depth of water withdrawn from tanks during the experiment	inch	19.38	27.30	17.38
Weight of metal in boiler	lbs.	44,100	44,100	44,100
Capacity of boiler, water being at water-line.	cubic foot	217.4	217.4	217.4
Diameter of cylindrical shell	foot	4.92	4.92	4.92
Total length of boiler	foot	22.31	22.31	22.31
Distance from water-line to top of boiler	foot	0.984	0.984	0.984
Horizontal surface of tanks in tender	square foot	73.59	73.59	73.59

giving the consumption of fuel per horse-power. Comparative tests with the various kinds of new locomotives ought to be made, and with the same accuracy. Unfortunately different drivers, working in the same circumstances and with the same kind of locomotive, show consumptions of fuel varying by from 10 to 20 per cent., according to their skill. This is a serious difficulty in making such comparisons between various systems of locomotive.

Comparison of practical results as to consumption with theoretical results.—The author will now compare the practical results in consumption of fuel with the theoretical results given by thermodynamics. This will give the measure of the improvement which remains to be made as regards the economy of fuel.

Efficiency of boiler.—We have seen that the boiler gives 8.08 lbs. of dry steam for 1 lb. of coal, at 128 lbs. per square inch pressure. Now, 1 lb. of water at 59 deg. Fah. requires 1169 units of heat to make 1 lb. of dry steam at 128 lbs. pressure. Thus, the boiler absorbs $8.08 \times 1169 = 9445$ units of heat for each pound of fuel, whose calorific power is 14,600 units, as stated above. The effi-

TABULAR SUMMARY OF EXPERIMENTS (*continued*).

	Items of interest.	Units.	18th July. Patent fuel Anzin.	20th July. Patent fuel Grand' Combe.	21st July. Patent fuel La Chazotte.
	Work of locomotive measured at circumference of driving wheels	foot-lbs.	770,600,000	810,100,000	705,900,000
	Apparent consumption of fuel	lbs.	1,116	1,286	1,094
Before firing the boiler at St. Jean-de-Maurienne.	Volume of water in boiler	cubic feet	251.34	252.04	250.98
	Temperature of water in boiler	degs. Fah.	293°	261°	255°
	Weight of water in boiler	lbs.	14,509	14,663	14,652
	Units of heat in water	British units	3,436,000	2,985,000	2,901,000
	Units of heat in metal	British units	1,175,000	1,012,000	988,000
	Units of heat in boiler, total	British units	4,611,000	3,997,000	3,889,000
After arrival at Modane.	Volume of water in boiler	cubic feet	182.40	223.41	180.64
	Temperature of water in boiler	degs. Fah.	257°	261°	232°
	Weight of water in boiler	lbs.	10,637	13,031	10,703
	Units of heat in water	British units	2,135,000	2,652,000	1,885,000
	Units of heat in metal	British units	1,008,000	1,024,000	885,000
	Units of heat in boiler, total	British units	3,143,000	3,676,000	2,770,000
	Loss in units of heat	British units	1,468,000	321,000	1,119,000
	Corresponding weight of fuel	lbs.	155	33	123
	True consumption of fuel	"	1,271	1,319	1,217
	Consumption of fuel per effective H. P. per hour	"	3.27	3.22	3.40
	Consumption of fuel per indicated H. P. per hour	"	2.88	2.84	2.99
	Weight of water lost by tender	lbs.	7,420	10,449	6,650
	Weight of water lost by boiler	"	3,872	1,632	3,949
	Total consumption of water	"	11,290	12,081	10,599
	Total consumption of water per lb. of fuel	"	8.88	9.15	8.68
	Weight of dry steam per lb. of fuel	"	8.08	8.32	7.90
	Ash in fuel	per cent.	6.90	9.70	9.60
	Moisture in fuel	per cent.	1.00	1.30	1.10
	Calorific power of fuel	British units	14,600	14,400	13,700

ciency of the boiler is, therefore, $\frac{9445}{14,600} = 0.65$. That is to say, the boiler utilizes in practice 65 per cent. of the heat given out by the combustion of the fuel, and loses 100—65=35 per cent. This loss is due to the following causes: (1) Loss of heat contained in the gases escaping at the chimney; (2) loss of heat by conduction to the atmosphere; (3) loss of heat by the presence of some little air in excess of that needed for combustion; (4) loss of heat by the escape of a small portion of carbonic oxide not burned into carbonic acid; (5) several minor causes. It is remarkable that the total loss of heat should be only 35 per cent. with so many causes of waste. One of the best improvements that can be applied to locomotives is the heating of the feed water with the exhaust steam. MM. Kirchweger, Mazza, Chiazzari, and Körting have designed several apparatus for that purpose. None of them have been a practical success, but the author hopes the want will be supplied before long.

Efficiency of the locomotive-boiler and engine together.—The quantity of work which a steam-engine can theoreti-

cally give out for one unit of heat* depends—(1) On the temperature corresponding to the boiler pressure; (2) on the temperature of the condenser. The maximum of work in foot pounds given by one unit of heat is $772 \times \frac{T' - T^2}{T' + 461.2}$. Here 772 foot-pounds is the mechanical equivalent of heat; T' is the temperature Fah. corresponding to the boiler pressure; T^2 is the temperature Fah. of the condenser, which in steam engines without condensation, is the temperature of boiling water; 461.2 is the number of degrees below Fah. zero of the absolute zero of thermo-dynamics. Applied to the present case of the locomotive, the formula gives $772 \times \frac{356-212}{356+461.2} = 136.$ That is to say, under such conditions, a theoretical steam engine would give 136 foot-pounds of work for one unit of heat. In practice we have seen that the locomotive gives 1 indicated horse-power per hour, or 1,980,000 foot-pounds for 2.88 lbs. of fuel, giving $2.88 \times 14{,}600 = 42{,}450$ units of heat. Thus the locomotive—boiler and engine—gives practically $\frac{1{,}980{,}000}{42{,}450} = 46.6$ foot-pounds for one unit of heat. The efficiency of the locomotive—boiler and engine—is, therefore, $\frac{46.6}{136} = 0.35.$

Efficiency of engine alone.—The efficiency of the engine alone is clearly equal to $\frac{0.35}{0.65} = 0.54.$ That is to say, the mechanism of the locomotive, receiving steam and giving out work, gives 54 per cent of the work which a theoretically perfect engine should give in the same circumstances. The loss of work is 100—54=46 per cent. This is due to the following causes: (1) Loss of work from the expansion of steam in the cylinders not being quite complete. (2) Throttling the steam, on entering or leaving the cylinders. (3) Back pressure of the steam during the return stroke. (4) Imperfection of the valve motion. (5) Condensation of steam during admission. (6) Leakages of steam, and several minor causes. Such are the many causes of the loss of work in the engine proper. The resulting efficiency of 54 per cent. is assuredly not so good as the efficiency of the boiler, which is 65 per cent.; still a loss of 46 per cent. is not very remarkable where so many causes contribute to produce it.

Comparison with a Corliss engine.—The author made a similar investigation with reference to a boiler and engine on the Corliss system, with condensation. The power was measured by an indicator; the consumption of fuel was also measured, and the results were as follows: Pressure in boiler, 5.5 atmospheres; temperature, 313 deg. F.; pressure in condenser, 0.9 atmospheres; temperature, 111 deg. F.; consumption of fuel per 1 H. P., 2.01 lbs. per hour; ratio of dry steam evaporated to fuel consumed, 9.5; calorific power of fuel, 14,500. The efficiency of the boiler and of the engine, compared with the theoretical results of thermo-dynamics, has been calculated, with the following results: Efficiency of boiler, 64 per cent.; efficiency of mechanism done, 53 per cent. These results are almost exactly the same as with locomotives, which give, as we have seen: Efficiency of boiler, 65 per cent.; efficiency of mechanism, 54 per cent. That is to say, the locomotive, compared with a theoretically perfect locomotive, is quite as good as a Corliss condensing engine compared with a theoretically perfect engine working as a Corliss engine. The author concludes that the locomotive is not so bad as engineers generally believe as regards economy of fuel. The general conclusion is that locomotives are not capable of much improvement as regards the economy of fuel, unless the pressure in the boiler can be increased. When the improvements in material and construction will allow the use of higher pressures, then a notable economy will be easily obtained in proportion to the increase in the value of the expression $\frac{T_1 - T_2}{T_1 + 461.2}$. But in that case the author considers it will be necessary to employ compound cylinders, or more complicated valve gear in order to obtain the best utilization and highest expansion of the steam. In concluding this paper, he wishes to add his tribute of admiration to those English engineers who have

* See "A Manual of the Steam Engine and other Prime Movers," by W. J. Macquorn Rankine. London, 1876, p. 343.

done so much for the existence and improvement of railways. To George Stephenson we owe the locomotive in its present form, the excellence of which, as regards the economy of fuel, is still worthy of admiration, while another eminent English engineer, Mr. Webb, is now carrying out a remarkable series of experiments, with the view of bringing it to its greatest possible degree of perfection. Having received from Mr. Webb himself details of his compound locomotive, which he has also had the pleasure of seeing at Crewe, the author is led to add here the few observations that have occurred to him in regard to this new kind of locomotive. If the boiler pressure be not higher than in ordinary locomotives, the author thinks the economy of fuel cannot be greater in the compound engine than in the best ordinary locomotives. With the ordinary boiler pressure of 9 atm., or 135 lbs. per square inch, the ordinary valve gear gives expansion enough, provided the cylinders be large enough, which is not always the case. The compound system lessens the injurious effect of the clearance spaces, and also diminishes the condensation of the steam during admission; but these two advantages are neutralized by the disadvantage of the steam being throttled in its passage from the first cylinder to the second, especially at high speeds. In other words, the consumption of fuel in a compound engine could not, in the author's opinion, be much lower than that given in the present paper, the boiler pressure being the same. This point would be readily settled by a few experiments on the consumption of fuel per horse-power per hour in the compound locomotive, including lighting up. The particular locomotives of ordinary class, with which the compound engine has been compared by Mr. Webb, appear to the author to be somewhat too heavily loaded for the best economy, their cylinders being smaller than those of the express locomotives on the Paris and Lyons Railway, which have cylinders of 19.7 in. diameter, and 24.4 in. stroke, with 6 ft. 6 in. driving-wheels. Fuel being very expensive on this line, the author's father always made his engines heavy, but very economical; and these express engines, which were designed by him and built at the works of the Paris and Lyons Railway, and of Messrs. Sharpe, Stewart & Co., are some of the most economical locomotives there are. The author has, indeed, made experiments, in which—on the same kind of line, and at the same speed, and with the same total weight of train—the consumption of fuel was almost exactly the same as in the latest experiments with the compound locomotive; but he cannot look upon such a comparison as of great value, because it is impossible to estimate precisely the difference of circumstances in the two cases. The further experiments he has suggested with the compound engine seem, therefore, to be needed for a fair comparison. In his own experiments the author has found 9 atm., or 135 lbs. per square inch, to be the maximum boiler pressure for obtaining good expansion with ordinary valve gear and with cylinders of ordinary size. With higher pressures, either better valve gear must be employed, or the compound system; and the latter is considered decidedly preferable by the author, who has shown that great economy of fuel can be obtained with a higher boiler pressure. In the compound locomotive the boiler is very light and very strong; and the author looks forward to the pressure of steam being yet further increased during the next few years, without making the engine too heavy for the rails. It will then be a necessity to adopt the compound system for obtaining good expansion; and the compound locomotive, without being too heavy, will then unquestionably be much more economical than ordinary engines could be, and will be well adapted for high speeds. Goods engines of the ordinary kind are not so economical in consumption per horse-power per hour as express engines; and the author anticipates, therefore, even better results from the compound system in goods engines than have been obtained with express locomotives. The compound system with yet higher boiler pressure, will thus, in his opinion, turn out to be the greatest improvement in locomotives since the time of Stephenson.

A NEW first-class Thornycroft torpedo boat, for the German Government, made the passage to Kiel, from London in fifty-two hours.

STORAGE BATTERIES.

From "Nature."

THE importance and desirability of an efficient and economical storage battery have been very widely recognized, but it is at the present time pretty generally felt that no existing form of storage battery is perfect, and that they are on the whole extravagant and wasteful to an extent sufficient to more than compensate for their undeniable convenience. It is perfectly certain that their employment has not become at all general, and that they have failed to realize the somewhat sanguine hopes of their early promoters.

It seems worth while to examine into the causes of this partial failure, and to inquire how far the evil opinion held by many practical men concerning our present method of storing electrical energy is justifiable.

One of the main objections is that storage involves a loss of some 50 per cent. of the whole. Now all methods of storing and transmitting energy involve some loss. To say that any particular method involves a loss of 50 or even 90 per cent. is not to condemn it utterly. There are many cases when the convenience of storage outweighs the evil of waste altogether; three principal ones may be specified.

(1) When the power of the source would be otherwise so completely wasted that every fraction of it stored is clear gain. This is the case of much terrestrial water power. The energy of the tides or of Niagara is enormous, and wholly wasted so far as human activity is concerned; if 50 or even 10 per cent. could be stored in such a way as to be conveniently available, it would be of considerable value, and any arrangement capable of effecting this storage could only with injustice be stigmatized as wasteful. The solar energy of the Carboniferous epoch has most of it been wasted; but a small fraction—probably not a millionth per cent.—has been saved and stored in the Coal-measures. It is possible to abuse the coal for not having stored more, but we find it a useful modicum nevertheless.

(2) A second case when the advantage of storage over-balances the loss is when regularity and continuity of supply is needed, and when the source is irregular and fitful. Wind and wave power illustrate this kind of source; it is manifest that wind power has not been so largely used as it would have been, had it been steady and dependable. A practicable method of storing up its energy and giving it out as wanted would gradually cause it to be very largely employed. This case is also illustrated faintly by a gas-engine or jerky motor of any kind, and the regularity and dependableness of a storage cistern may very well make it desirable to put up with some waste provided it be not excessive. Mechanical devices for approximating to regularity, such as the use of slack driving belts, undoubtedly give rise to a waste of power, and so does any form of regulator. But in the utilization of artificial forms of power like this, questions of economy become almost pre-eminent; and wastefulness is here a most serious objection, and, it may be, prohibitive defect. At the same time, if the engine is liable to stop, or if it is not always working, some mode of storing energy may be absolutely necessary, whether wasteful or not.

(3) Another case, and to some extent the converse of the last, is when the available source is weak, though continuous, while the power is only needed for a short time, but during that time is required to be great. This is exemplified in the operation of pile-driving, where energy is stored in the slowly-raised weight to be suddenly expended on the head of the pile, also in the operation of drawing a bow; or again, when a small waterfall or steam-engine, running continuously, is to be utilized for lighting during five or six hours each day; the obviously right plan in such circumstances as these is to store the energy during the hours it is not wanted, and thus virtually to double or treble the power of the source while it is actually in use. Unless, however, the loss occasioned by storage were reasonably small,

there would be but small gain in attempting the process in this third case.

It is plainly advantageous to devise a method of storing that shall give out the greater part of what is put in; but we see by these examples that a reasonable loss may be more than compensated by convenience, regularity, availability and dependableness. Again, when energy has to be transmitted over great distances, it is in practice difficult or impossible to make the expenditure of energy at one end depend upon and be regulated by its consumption at the other; and so, without some system of storage, great waste will ensue during intervals of small consumption. Looking to the immense development which the transmission of energy may be expected to undergo in the course of the next few decades, a convenient and manageable method of receiving large quantities of transmitted energy, and of holding it in readiness until wanted, must be of prime importance.

It was in view of such applications as these that the invention of the storage by Faure was hailed with enthusiasm by the highest scientific authority in Great Britain; while the public, jumping to the conclusion that a thing for which so many uses could be instantly found must needs be a profitable investment, hastened to provide money, not for commencing careful experiments and perfecting the arrangement, which would have been wise, but for manufacturing tons of apparatus in its first crude, immature, and untried form. Some day it may perhaps be recognized that because it can be shown that a thing will be extremely useful when perfect it does not follow that it has already attained that perfection, that indeed probabilities based on historical developments are enormously against such abnormal and instantaneous maturity, and that the careful nursing and rearing necessary to healthy maturity are better given in the seclusion of laboratory and study than in the excited and heated atmosphere of the Stock Exchange. It is doubtless recognized already that all preliminary operations are better conducted on a scale smaller than the wholesale manufacturing one. In developing a new industry there are scientific difficulties to be overcome, and there are manufacturing difficulties. By scientific difficulties we mean such as the determination of weak points, the best ways of strengthening them, and generally the discovery of theoretically the best modes of effecting the object in view; manufacturing difficulties begin with questions of expediency and economy—how most cheaply and satisfactorily to carry out the indications of theory, to obtain this or that material—and include the organization of a system of manufacture, of division of labor, of machine tools, which shall enable the work to be done with economy, security and despatch. Overhaste in the preliminary stages causes both these sets of difficulties to be tackled together, and so throws a grievous burden on both adviser and manager. All these untoward conditions have storage batteries experienced; and to say they have not fulfilled the hopes of their early promoters is no more than to say that those hopes were untimely and unreasonable. The period of maturity has been undoubtedly delayed by injudicious treatment, but its ultimate attainment seems to us inevitable; and it is at present a matter of opinion how nearly it has already been reached—certainly great steps towards it have been made. Let us inquire what some of the difficulties encountered have been, and it will be seen that, formidable as some of them are, they belong essentially to an infantile stage, and are not suggestive of constitutional debility.

The first form of manufacture consisted in rolling up sheets of lead and composition, with trousering to keep them separate. The difficulties found were that the coatings would not adhere, but became detached in large flakes; that the trousering got corroded through and permitted short circuiting; and that free circulation of fluid being impossible, the acid became exhausted in some places and concentrated at others, and thus every sort of irregularity began. Now regularity or uniformity is of the most vital and fundamental importance in any form of battery. If any part of a plate is inactive, that part is better away; if any plate in a cell is inactive, it is better away; and if any cells of a battery are inactive, they are infinitely better away. The rolling or coiling up of the sheets being found awkward in practice

and liable to detach the coatings, flat plates came to be used, then perforated plates, and then cast grids; these last having such large hole space that they held enough composition, and held it securely enough, to enable the trousering or intermediate porous material to be dispensed with. This was an evident step in advance: free circulation of the liquid became possible, and could be assisted by stirring; there was nothing to corrode except the plates themselves, and the composition, being in the cells or holes of the grid, might be reasonably expected to adhere. So far expectation was not altogether belied. The adhesion was not perfect, it was true, and pieces of composition sometimes fell out of the holes, especially if too powerful currents were passed through the cell, but still it was much better than it had been; and if the plates were well filled, properly formed, and fairly treated, the composition adhered extremely well and securely. The circulation of the liquid was not automatically perfect either, but mechanical agitation could be readily applied; without it the acid near the bottom of the cells tended to become more concentrated than that near the top, not by reason of gravitation undoing diffusion, which is impossible, but because during each charging fresh acid is formed, and in great part falls to the bottom in visible streams. Another great advantage was that some amount of inspection of the plates became possible, and experience as to the actual behavior and appearance of the plates, began to be accumulated. And painfully varied that experience was. Every variety of extraordinary behavior which could be suggested as probable, and a good many which no one could possibly have imagined beforehand, made their appearance. The hundreds of tons of batteries made at this period doubtless enabled these unpleasant experiences to be more rapidly acquired than would have been done on a small scale, but it was a costly series of experiments. However, the experiments were made, the public involuntarily assisted in the acquisition of experience, and, caring less for knowledge than for marketable commodities, they expressed dissatisfaction at the result. Many of these incipient difficulties are now overcome by the manufacturers, but the great dislike of the public to involuntary experiments, and the shock which their confidence underwent on being unexpectedly called upon to participate in research, have not yet altogether abated.

The main difficulty now experienced was how to keep the plates from touching. They might be put in wooden frames, or elastic bands might be stretched round each of them, and if they would only keep flat it was impossible they should touch unless the composition should drop out of the holes. Sometimes the composition did drop out of a hole, and bridge across the interval between two plates, but the more common and more fatal experience was that the plates would not keep straight. In a few months the positives were found to swell, and as they swelled to buckle—to buckle and twist into every variety of form, so that elastic bands, wooden frames, and every other contrivance failed altogether to prevent short circuiting. The cause of the buckling is, of course, irregular and one-sided swelling, and the cause of the swelling is apparently the gradual peroxidation and sulphating of the material of the bars of the lead grid, which occupy less room as metallic lead than as oxide or salt. As the bars swell, they press on the inclosed composition, occasionally driving it out, but more frequently, and with properly made and treated plates universally, distending themselves and stretching the whole medial portion of the plate. The edge or frame of the grid is stronger than the middle bars, and is not so easily stretched; in a good and uniformly worked plate it does stretch, and an old positive plate is some quarter of an inch bigger every way that a new one, but if one face of the plate is a trifle more active than the other, it is very plain that the most active side will tend to become convex; and buckling once begun very easily goes on. To cure it two opposite plans have been tried: one is to leave the plates as free and unconstrained as possible, hanging free, it may be, from two points, thin, and with crinkled or crimped margins to allow for expansion; the other is to make them thick and strong, with plentiful ribs for stiffness, and besides to clamp them up one to another as tightly as may be, and thus in mechanical ways to resist buckling and distortion. I do not know that any one

could say for certain beforehand which of these two plans would be likely to answer best, but practice is beginning to reply in favor of the latter, and well braced plates of fair thickness show no unmanageable tendency to buckle. It must be remembered that no material can buckle with a force greater than that necessary to restore it to flatness, and this force in the case of lead is very moderate. Hence it may be fairly hoped to overcome and restrain all exuberances by suitable clamps and guides arranged so as to permit flat and even growth, but to check all lateral warpings and excrescences.

Uniformity of action is still essential, especially if all the plates in a cell are clamped together. Plates mechanically treated alike ought to be electrically so treated also, and it is impossible to keep a set of plates working satisfactorily together unless the contact of each is thoroughly and equally good, so that each may receive its fair share of current. Defects of contact have been a fruitful source of breakdown and irregularity. Clamps and screws of every variety have been tried, but the insidious corroding action of nascent oxygen exerted through the film of acid which by spray and creeping forms and concentrates on the lugs—this corroding action crawls between the clamped surfaces, gradually destroys all perfect contact, and something produces almost complete insulation. Contacts on the negative plates give but little trouble; contacts on the positives have taxed a great amount of patience. Lead contacts "burned," *i. e.*, melted, not soldered on, are evidently less liable to corrosion than brass or copper fittings, or than any form of clamp, but they are apt to be somewhat clumsy if of sufficient conductivity, and moreover they are awkward to undo again, and somewhat troublesome to do. However they have proved themselves so decidedly the best that now no other contacts will be used, and their re-introduction has been followed by a marked improvement in the behavior of the cells. So long as contact with one plate was better than with another, a thing quite possible to happen without any difference being perceptible to the eye, so long was it possible for one or two plates to remain almost wholly inactive while another one or two received far more than their share of current, and became distended, warped, overcharged and ultimately crumbled away. If one or two plates in a cell are black, and giving off torrents of gas, while the rest are brown and idle-looking, it is pretty fair evidence of irregular and insufficient contact, or else of some great discrepancy in the age or make of the plates. This point also is one that was not attended to in the early stages of manufacture; plates were made for stock, and cells were made up with plates of all ages selected at random from the store. Directly uniformity is perceived to be essential, this is recognized as obviously bad. Plates intended to work together should be of the same age and make, and inasmuch as keeping does not improve them, the best plan is not to make for stock, but to keep material ready, and then quickly make up as wanted. Plates in work deteriorate slowly, but they are wearing out in the fulfillment of their proper function; plates in idleness deteriorate as quickly, and they are rusting out in fulfillment of no function at all. Worn-out plates, however, are by no means valueless. Lead material has a well-recognized price, and if attention were given to the subject, it is probable that decrepit and useless plates might be made to yield a very large percentage, if not the whole, of their original lead. For it must be remembered that plates deteriorate not by waste but by accretion: an old plate contains as much lead as a new one, but it contains it with the addition of oxygen and sulphion; no longer a tenacious coherent frame, but a crumbling mass of incoherent powder.

The age of plates is a point of vital interest, though but little is known as to the possibilities in this direction at present. A year may be regarded as a fair average age at the present time; but this is a low rather than a high estimate. Thick plates are found to last far longer than thin, which is only natural when it is remembered that the wearing out is due to corrosion, that corrosion proceeds mainly from the surface inwards, and that the internal portions of a thick plate are to a great extent protected by the mass of superincumbent material. If it can be shown, as we understand it can, (1) that the cost of materials is far more

than the cost of manufacture; (2) that the worn-out material has a market value not incomparably less than the original; and (3) that the frequency with which plates have to be renewed is not such as to cause much inconvenience; then we hold that the first stage of the durability difficulty has been overcome. Much more may be hoped for in this direction as experience increases, and it is not extravagant to hope that a well-ribbed, properly-clamped, and fairly-treated thick plate may last as long as five years before it becomes disintegrated.

It is evident, however, that in a region where pure experiment is pre-eminent, and where the units of time are months and years, instead of hours and days, the accumulation of experience is a slow and tedious process. It is no use making statements involving periods of five years when no one has had the present improved form in use for so much as six months. Nevertheless it is possible to see that the present cells are better than their predecessors; and as their predecessors have lasted in good condition for a year and more, it is not presumptuous to indulge in well-founded hopes. Many of the difficulties connected with the early forms of battery were aggravated by Utopian notions concerning internal resistance and compactness. The internal resistance of a cell was so beautifully small, that the manufacturers were tempted to diminish it still further by putting the plates far too close together. An eighth or tenth of an inch interval is well enough if the plates had been hard rigid slabs of perfect flatness; but it was madness to pack flexible lead plates full of composition certain to swell and liable to drop out so near together as this. Security and dependableness were sacrificed to a natural desire for sudden and Utopian perfection. We may hope that these lessons have been profited by, and that the manufacturers perceive that confidence and security are the first conditions of success, and that minutiæ as to the number of noughts before the significant figures in the specification of resistance begin, though those also are of importance in their turn, are yet of quite secondary consideration. Moreover, this packing of the plates so closely did not really do much to secure the result desired; the greater part of the resistance of half run-down cells is not in the liquid between the plates, but in the surface or scum separating each plate, and especially each negative plate, from the liquid, and hence putting the plates a safe distance, say a quarter or one-third of an inch apart, exerts an effect on the total resistance which is certainly far more than compensated by the ready opportunity thus afforded for access by both sight and touch. The old opaque boxes chock full of plates, with slight india-rubber bands between them, were started and left to Providence. No one could see what went on, nor could one readily get at anything to rectify what was wrong. In the present glass boxes properly arranged on accessible shelves with only plugs or studs between the plates, clear vision through the cell in any direction is easy, and accidental obstruction not only very seldom occurs but if it does it can without difficulty be seen and removed. But it must be granted that these boxes are less compact than their predecessors, and for some purposes, such as locomotion, compactness is of the first importance. Most true, for some purposes. It is not to be supposed that one type of cell will answer every possible demand. A dynamo to be highly efficient must have a large and massive field magnet, but in some places bulk and weight are fatal objections, and in these places smaller and more compact dynamos may be more suitable: something, however, must be given up to secure the required lightness and compactness, some sort of compromise must be effected. Just so with cells: we can point out what is theoretically the best form, and this form may, for large stationary electric light or power installation, be actually the most suitable; but we may also see that for boats, for tramcars, and for fish torpedoes, some very different and far more compact form may be quite essential.

Efficiency, durability, economy, compactness: it may not be possible to attain all these at once—if it were, there would be small room for discussion—but sometimes one and sometimes another will be the pressing necessity, and manufacturers of storage batteries, like manufacturers of dynamos, must be prepared with forms suited to various needs.

We have spoken mainly of difficulties

connected with the positive plates, and have said nothing concerning the negatives. It is not that these are not susceptible of improvement, but their faults have been of a less imperious and obtrusive nature. They are not perfect, but they do fairly well, and there has been little need to worry much about them, until the extraordinary behavior of positives had been taken in hand and checked. The time is coming to attend to these also. They fail not from exuberance, but from inertness. As they grow old, they do not swell, and warp, and burst, and crumble, like the positives, but they grow quietly hoary, and serenely decay. The composition in a worn-out negative consists of white sulphate through and through, but the frame remains intact, and it consequently never falls to pieces, nor does it swell. Impurities in the acid used tell upon a negative plate—nitric acid is fatal. Acid much too weak or very much too strong is also deleterious, and idleness is bad. The difficulties connected with negatives mostly depend on their aggravating property of always requiring a quite opposite treatment to positives. The less a positive is formed and overcharged the better. A negative delights in complete formation and frequent overcharge. In recognition of this it is now customary to form them separately, and to give the negative a thorough dose of hydrogen without commencing the corrosion of the positive by an overdose of oxygen. When the discharge from a cell begins to flag, it is the resisting scum of sulphate that has formed over the negative plate which is responsible for the flagging. The true E.M.F. of a cell is wonderfully constant throughout the whole discharge; but the internal resistance is all the time increasing, at first very slowly, ultimately, towards the end, with a rush. One such run-down cell in the midst of a lot of others, therefore obstructs the current terribly. If only a series of cells could with certainty be made to work together uniformly, if a series could behave as well as some of the cells in it, no one would have cause to complain.

Through the whole history of the manufacture, from the very beginning, a few cells here and there have always exhibited astonishing efficiency; the aim of manufacturers may be said to be to bring all cells up to the level of a few. Much progress in this direction has been made, and it may be very fairly expected that, as uniformity is gradually attained, a series of cells subjected to the same treatment may behave in the same manner. Whenever this is certainly accomplished, there will have been reached a high stage of efficiency, beyond which further progress need be only in the improvement of comparably insignificant minutiæ.

The subject of the electrical storage of energy is really one of national importance; it is comparatively a small matter whether this or that form of storage, or this or that company of manufacturers, succeeds in bringing out the permanent form. It sometimes unfortunately happens that enterprising pioneers only clear the way, and retire just in time for other men to come in and reap the fruits of their labors. So much capital and so much labor have been already expended in the effort to bring storage batteries to perfection, so great progress has been made, and so apparently small are the steps which yet remain to be accomplished, that we may surely fairly hope that some of the original believers in their great, and as it seems to us inevitable, future may yet live to see their faith justified and their patience rewarded, and may even taste some of that so-called "substantial" reward without the hope of which great commercial enterprises would never be undertaken, and modern civilization would have scarcely yet begun.

The following is from a German patent, No. 20,939, for a method for the manufacture of artificial gutta-percha: About 50 kilos. of powdered gum copal, and from 7½ to 15 kilos. of flowers of sulphur are under continual agitation heated in a boiler with double the quantity of turpentine or with from 55 to 62 liters of petroleum to a temperature of 125 to 150 deg. C. till completely dissolved. The mixture is then allowed to cool down to about 38 deg. C., when a solution of 3 kilos. of caseine is added, the latter being dissolved in weak ammonia with the addition of a small quantity of alcohol and wood spirit. The mixture is now heated for a second time to the same temperature until it assumes the consistency of a thin fluid. It is then boiled with a solution containing from 15 to 25 per cent. of tannic acid—galls or catechu—to which ½ kilo. of ammonia has been added. After having been boiled for several hours the mass is allowed to cool, washed with cold water, and kneaded out in hot water. After this treatment it is rolled out and dried.

NOTES ON THE CONSTRUCTION AND EQUIPMENT OF NARROW-GAUGE RAILWAYS.

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When asked by the committee to prepare a paper on narrow-gauge railways I consented; but, on looking over the subject, I find so little to be said, except as to cost, that will not apply equally well to any railway, that I will simply note a few points on their construction and equipment in general, and then give you, somewhat in detail, the various items of cost particularly applicable to narrow-gauge roads, hoping they may be at least interesting to the members of the association, though I do not think they will be particularly instructive to those whose experience is largely in railroad work.

Location.—The question of location I need not allude to, except to refer you to the able paper on the subject read by Mr. Hodgman at your last meeting. His treatment applies as well to roads of one gauge as another. I will say, however, that curves and grades on narrow-gauge roads are just as objectionable as on any road; although sharper curves may be used, they should be avoided as much as possible.

Supposing our location to be completed, and grades established, we are ready to proceed with construction work; we will also suppose that the contract is drawn in proper form and the work let, subject to the proper specifications, as we are dealing more directly with the work of the engineer and the contractor.

Clearing and Grubbing.—The first work to be done is the clearing of the right of way and grubbing for the road bed; clearing should be done the full width of the right of way, whatever that may be, and all the logs, brush, and perishable matter be piled and burned, so as to be out of the way of the workmen as well as the contractor; as instances have been known where contractors have been tempted at least to use the logs, stumps, etc., lying along the right of way, for making the road-bed, which is not desirable except in special cases. The engineer should furnish the contractor, for use in clearing, notes of stations between which grubbing should be done, and width of grubbing, so that he may do no useless work and may do grubbing in connection with clearing, as a standing tree is much easier to grub out than a stump. All stumps and grubs should be taken out where the sub-grade line is within two feet of the surface, also on all cuts. Where the fill exceeds two feet low chopping will suffice, and in fills of four or more feet, stumps of ordinary height are not very objectionable and may be left standing, except where they are very large and decayed, when they should be removed.

Cross-Sectioning.—Clearing and grubbing completed, the engineer is ready to do his cross-section work, which consists in putting in stakes every 100 feet, or oftener if the surface of the ground is uneven, which stakes are set one in the center and one at the edge of each slope. Each stake should be plainly marked on one side with the number of the station at which it stands, and on the other with the cut or fill to sub-grade at the point where it stands. They should be set uniformly, the center stakes exactly on the center line, with the station number facing the backward direction of the line, and the slope or side stakes set at right angles to the line even with the center stakes, with the cut or fill facing the line. On uneven ground, plus or partial stations should be put in in the same manner as the regular stations, and the full station number should be put on each plus stake; thus a cross-section midway between stations 79 and 80 should be marked not simply +50 but 79+50. A little care in this direction will save a great deal of annoyance and time in subsequent work when stakes are knocked down by careless workmen and have to be replaced, possibly when the notes are not at hand. At every point where the grade and surface lines cross, there should be set a *grade stake* marked 0.0 or grade; this should be done not only

at the center but on each slope, and the plus station at which each occurs carefully noted.

Each cross-section should be carefully recorded in a cross-section book: the usual form being to place the center cut or fill in a central column, and left and right slopes in a column at left and right of the center in the form of fractions, with the cut or fill as the numerator, and the distance out from the center line as the denominator, with their respective signs, plus for cut and minus for fill, thus:

L.	C.	R.
$\frac{-2.0}{9.0}$	+3.5	$\frac{+3.6}{13.4}$

showing a cut of 3.5 at the center, a cut of 3.6, and a distance out of 13.4 on the right and a fill of 2.0 with a distance out of 9.0 on the left. These distances apply to a road-bed of 12 feet on fills and 16 in cuttings with a slope of $1\frac{1}{2}$ to 1.

Experience has proved that there is no economy in building narrow road-beds. We commenced on the Port Huron and North-western Railway by making fills 8 feet at sub-grade and cuts 12 feet; then we widened banks to 9 feet; on our next work we made banks 10 feet and cuts 14, and now build banks 12 feet and cuttings 16 feet, which are none too wide, and are found to be more economical in the end.

As I believe the papers which are read from time to time before this association are intended to be of practical use to the members, rather than finished literary or scientific productions, let me give what I consider the best method of doing cross-section work. I have noticed that beginners almost universally use the cumbrous method of figuring out each station by itself from the height of instrument and grade height, a tedious as well as unnecessary work. First, set your level firmly, and in such a position as to command a good view of your work; bring it to a level, and take from the nearest bench mark a reading, which add to your bench height to give you the height of instrument. Now, from your cross-section book, note the grade of the station at which you propose to commence your work. The difference between your instrument height and grade height will be the reading of your rod at that station held at grade, and the difference between it and the actual reading at the point will be the cut or fill at that point.

To illustrate. Your bench-height is 80.10; your rod on bench mark reads 5.08, making height of instrument 85.18; your grade height at station 79 is 82 00; so your rod held at grade at station 79 should read 3.18. But suppose it actually reads 5.30; then your fill is 2.12; if it reads less than 3.18 you have a cut. If you are working on a level grade, all your grade readings will be the same, and you have no trouble; but if, for example, you are working on a down-grade of 26.4 feet per mile, add to your rod 0.5 for each station, which would give you 3.68 at station 80, and the difference between that and the actual reading will give you the cut or fill. Then you can keep on adding to or subtracting from your rod reading at grade the change for each station, and work from rod readings at grade entirely, paying no attention whatever to your height of instrument or grade height until ready to move your instrument, when you begin over again. In this way one can soon become so familiar with the work that he can call off and record his work as fast as a rodman and two smart men can measure the distances, mark and drive the stakes.

In cross-sectioning at changes of grades, especially when the changes are abrupt, vertical curves should be put in, extending from 1 to 3 or 400 feet each way, so as to avoid bringing the connecting grades to a point. This introduction of vertical curves is very little extra trouble in connection with the other work and should not be neglected. It is also advisable, though not a necessity, to put in at each regular station, where fills are to be made from side ditches, *berm stakes* the specified distance out from the slope stakes, as workmen are less liable to cut away the berm if stakes are driven for them to work to.

Earthwork. — Cross-sectioning being done at any given point, the work of grading may be commenced. I have known of grading being begun without any cross-section work, or even the center stakes being in, but cannot say it was a success. Fills should be made from the adjoining excavations within an economical distance for hauling, which

distance varies with circumstances. The embankment should be carried up uniformly from the bottom from full width, so as to prevent sliding or uneven settling. Fills made from cuts by the use of dump-cars can be carried up uniformly by shifting the track as may be required; where fills are made from side ditches the latter should be taken out continuously so as to make clear waterways where necessary. The usual slope given to ordinary earthwork of sand, clay, or loan, is $1\frac{1}{2}$ feet horizontal to 1 foot vertical, although varying circumstances may make a greater or less slope desirable. In cuts, the slopes should be smoothly dressed and uniform; in each cut, however small, there should be side ditches to carry off the rain-water, or that which soaks in from the sides; the ditches should have a surface width of one-half the difference of the width of cut and fill at sub-grade, leaving, as it were, an embankment through the cut, so that, when the earthwork is completed, the grade presents an unbroken surface of uniform width. It is not always advisable during the process of construction to take out cuts to the full width, or even down to sub-grade; when the material may be used for ballast the cut may be *gulleted* or taken out just wide enough to admit the passage of a train, and with slopes of $\frac{1}{2}$ to 1, or even steeper, if the material will allow, and the remainder of the cut taken out with trains. In certain cases it is advisable to build narrow banks at first, to be widened later on.

Across all swamps and marshes soundings should be taken to determine the nature of the ground and the depth to firm bottom, and, in case the foundation is not good, some means should be taken to improve it. Where it is not too soft or too deep, a good method is to corduroy with timber laid cross-wise of the road-bed with brush thrown on; the length of the timber necessary may be judged from the nature of the ground and the weight of embankment to be built. In some cases it is necessary to drive long piling, and some swamps are so deep that it is almost impossible to build across them with any reasonable expense, such places should be avoided if possible. Across some swamps and marshes very little or even no material may be obtainable to make a bank. I have recently, in my own experience, met with a swamp $2\frac{1}{4}$ miles across, which was, in the direction of the line, a level surface; soundings showed a firm bottom 6 to 18 feet below a fairly firm muck; but the season was very wet, and an attempt to throw up a bank of muck was a failure, as it would run off a shovel before it could be thrown up. In this case I took the small poles and brush from the right of way and laid them along the center line cross-wise, and then some small poles, from 2 to 6 inches in diameter, lengthwise, so that they would come under the ties outside the rail; on these I laid the ties and iron for a good share of the distance across the swamp, with no earthwork whatever. After the track was laid across (it was not very smooth however), we turned back and filled with clay and raised the track; soon it will be one of the best pieces of track on the road.

Culverts.—During the process of locating and constructing, the engineer has looked over his line and its contiguous territory closely, to determine the location, size and character of the necessary water-ways, and during his cross-section work has probably staked out his drains, culverts and bridges, made out his timber bills, and made provision for the timber and material for the various structures. In places where there is but a small area of surface drainage, and no danger of an accumulation of water, a small drain of sewer-pipe may be made, or in cases where cheapness of construction is necessary, which too often happens, a simple box of plank, spiked together, will answer where the embankment is light. Where there is much water a culvert should be put in. On new work in new countries wood is almost entirely used, leaving the more expensive as well as more desirable stone and iron structures to be put in when the first have had their day, and the other can be brought to the spot by train, and the company have presumably more means to do work with.

Ordinary culverts are built of $12'' \times 12''$ timber; I use $10'' \times 12''$ on edge, the sticks laid one upon the other, secured by dowel pins. The foundations are usually ordinary mudsills of flatted timber, sunk in the ground below the bottom

of the waterway, to avoid undermining. The sills should be boxed down at the ends for a couple of inches to prevent the wall sticks from sliding in from the pressure of earth behind them. The top wall piece of an open culvert should be 4 feet longer than the width of embankment of sub-grade, and each succeeding stick 3 feet longer than the one above it till the surface of the ground is reached. The walls should be braced against the thrust of the earth behind them by struts across from one wall to the other, usually dove-tailed into the wall sticks. Culverts should be laid out so as to have the top of the walls reach just to sub-grade; on these walls are laid the track-stringers, lying loose so as to be brought to the required line or shifted at any time. When open culverts are more than 8 feet wide they should be made with a bridge top, *i. e.*, with ties across the stringers. Box culverts are made as above described, but are covered with either plank or timber, and usually with the earth of the fill. Across small streams the ordinary pile bridge is the cheapest and best to build. Use white oak piles, not less than 10 inches in diameter at the small end, well driven; the usual plan has 4 piles in a bent, the bents from 12 to 16 feet apart (14 feet is a good distance), the piles sawed squarely off and the cap securely drift-bolted on top of the piles. Where the height does not exceed 12 or 15 feet the piles may answer as bents, and the track-stringers be laid directly on the caps; but where the height is greater there should be trestle-work on top of piles. Across larger streams, or where there is danger of freshets, ice, driftwood or logs, there should be a clear span to leave the channel unobstructed; on navigable streams a draw-bridge becomes necessary. For ordinary trestle-work, timber of the following sizes may be used: Caps 10×12, main posts 10×10, batter-posts 8×10, stringers 7×14, lateral braces 6×6, sway braces 3×10, girts 6×6, ties 6×8, guard rail 6×6. These dimensions will suffice for narrow-guage roads using engines of 18 to 20 tons weight; we have latterly built our bridges of the usual standard size.

Track-laying.—In advance of track-laying the engineer should carefully retrace his line along the grade, and put in solid stakes for track centers. These stakes should not be less than 2 inches square, well driven, left 6 to 8 inches above the surface of the grade, and having a tack or nail showing the exact line on the stake. On tangents center stakes 200 feet apart will suffice, but on curves they should be put in every fifty feet. Centers should be put on all culverts, and at intervals of 10 to 20 feet on all bridges. We will now suppose the centers in, the material all ready, our forces and construction trains at hand, and will proceed with work. First, we must load one train with the proper proportion of iron, ties, bolts, straps, spikes and tools; the car for bolts, straps, spikes, etc., is usually the head car, then come the ties, then the iron. The train is backed out to the end of the iron, and when the track-laying force is ready, as many rails and ties as will make a lorry load are thrown off, together with the necessary spikes, bolts and straps, and the train pulls ahead out of the way. The lorry men run their car back and load, say, ten rails; above the rails, but placed so as to leave the rails loose, are loaded a sufficient number of ties for as much track as the rails will lay, and bolts, spikes and straps enough for ten joints. Then the lorry is run ahead to the end of the rails, where the men, standing in a row on each side, pass forward the necessary number of ties for a rail length, laying them evenly and properly spaced on the grade, being guided by a line stretched along the grade and a pole properly spaced; a large tie should always be selected for the joint. Next, on each side, the forward gang grasp the end of a rail and pull it forward, and, as the rear end drops from the lorry, it is caught by the rear gang and placed at the end of the rail in the track, then the forward end is dropped to line; this is done on each side simultaneously; the lorry is then run ahead to the end of the two rails just laid and the process repeated. While this work has been going on, another lorry load of iron and ties has been loaded and brought forward, the empty lorry tipped on its edge off the track to allow the other to pass, which, in its turn is unloaded and sent to the rear for another load. For laying light rails three men at front and two at rear on each side is force enough; for heavy iron more are necessary. As the iron

and ties have been run out from the lorry a pair of straps, with the necessary bolts, has been left at each joint, and two spikes dropped at each end of each tie.

Immediately in the rear of the lorry come the *strappers*, who quickly place the fish-plate, or whatever joint fastening may be used, on the joints, and bolt them to place, leaving the proper expansion at each joint; then come the *spikers*, working two together, the two on the line side ahead, spiking usually the joints, quarters and centers. Before the train is run upon the track each rail is spiked to the tie exactly to a line which a boy has previously chalked on it a certain distance from the end, measured by a short stick, so that when the rail is full spiked and lined, the line end of the ties are in a true and even line. The rail joints should be kept exactly opposite to each other, except on curves, when joints should be opposite centers on narrow-gauge track, as it thus retains its alignment much better. Two spikers are also at work on the other side, using a gauge, and quickly spiking the rail to place; each set of two spikers have with them a *nipper*, or a man with a light iron bar and a block of wood, whose duty it is to hold the tie to the rail while being spiked. Spikes should be driven squarely into the ties so as to have a firm bearing against the rail, both on the side and head of the spike, and should be driven, not in the center of the tie or exactly opposite on the side of the rail, but one a little ahead of the other, but both inside spikes should be driven alike, *i. e.*, either ahead or back of the center of the tie, as it prevents the tie from *rocking*, which it will do if spiked otherwise. As soon as the track is laid and spiked at the joints, quarters and centers, the train may be run up and kept closely following the workmen. Behind the train come the back spikers, who complete the spiking, and then the *liners*, who throw the track into line, when it is ready for the ballast train. Track-laying is often partially done by machinery, by means of adjustable rollers fastened to the sides of the car, on which the iron and ties are carried to the front along the side of the train; also by a lorry car running on a track on the supply train. Each method has its advantages, especially where men are scarce.

Ballasting.—As soon as the track is laid the engineer should run his ballast grades, which should be marked by good stout stakes set at the side of the grade, at the foot of the slope of the ballast opposite the center stake, and driven so that the top of the stakes should be as high as the top of the rail at final grade; stakes 200 feet apart on tangents and 50 feet on curves, the same as centers, will answer. The ballast train should consist of as many flats as can be conveniently used and handled, varying with the condition of the pit for loading, the capacity of the engine for hauling, and the force used to do the work. The most economical method, when a convenient pit of material is reached, is to lay a temporary track (or, what is better, if it can be done, two tracks into it, by which much time will be saved in shifting trains), then load one train while the other is on the road. Unloading is most economically done under ordinary circumstances by means of a plow worked by a wire cable from the engine, when no time is lost by men riding back and forth between pit and unloading point, as the train force is sufficient to handle the plow, and the pit force can be adjusted so as to load while the train is making a trip. An estimate of the quantity of ballast to be used should be made, so that the trainmen may make a proper distribution of it. Allowing the surface to be uniform at sub-grade, the quantity of ballast to raise the track to final grade can be determined very closely and distributed accordingly, so that, when the surface is complete, very little or no ballast will remain unused.

In raising track it should first be lifted to final grade at each grade stake and securely packed; then by use of sighting boards, the joints and centers between the two points are raised to the same grade, except on the vertical curve before alluded to when the intermediate points should be rounded to agree with the curve. On horizontal curves the outside rail should be raised; on 3-foot gauge we raise the outer rail $\frac{3}{8}$ inch for each degree of curvature up to 5°. All points of the track having been raised to the proper height, and the ballast shoveled in and well tamped the entire length of each tie, the track is ready for lining. A liner and three or

more men with lining bars throw the track carefully to the exact center as indicated by the tack head in the stake driven before track laying; then all parts of the track are thrown to correspond, and the rail brought to a true line. One side (it is not essential which) should be taken as the line side, and all lining of ties, iron, or track be done on that side. Following the liners come the finishers, who properly distribute what material may be left by the surfacing gang, and give the required surface to the ballast, dress it up neatly, remove any ballast from the ditches in cuts, and gather up in shape for removing any surplus material. Different companies have different forms of ballasting and dressing. Some raise the ballast nearly as high as the top of the rail in the center and slope it to the lower edge of the tie at the end; others keep it nearly level with the top of the tie in the center, and nearly as high at end of the tie, and others still have other forms; but on narrow-gauge track it is essential that plenty of ballast should be at and against the ends of the ties, otherwise it will be very difficult to hold the track in line.

Very many points of work have not been alluded to at all, although they all have an important bearing upon the work. We have not mentioned at all what is important, especially to the contractor, monthly and final estimates, also the manner of making them, building of bridges, crossings, etc., and the thousand and one other matters that enter into the work of construction.

Equipment.—But let us consider our road-bed and track as completed, ready for the running of regular trains, and mention some of the necessary equipment for doing business. Of first note is the rolling stock, consisting of locomotives, passenger coaches, baggage, and express cars, box cars, flat and stock cars. The locomotives should, of course, be adapted to the service for which they are intended; those for the passenger service should have a larger wheel and quicker motion than those for freight; so of the other rolling stock, it should be adapted to the class of business required; but I leave the subject of rolling stock for some one better acquainted with it than I am, and mention briefly some of the equipment which more directly concerns the engineer, such as water stations, passenger and freight buildings, shops, engine houses, turn-tables, etc.

About the first essential is the water supply for engines. During construction work, the engines may be supplied with water pumped by hand directly into the tender tank, or better still by a small steam pump, which may be shifted from point to point, or yet again by a steam siphon and hose carried with the engine, the hose of which can be dropped into any convenient ditch or pond of water by the roadside; in case of emergency, water may be bailed up with pails. All these processes are slow and tedious, and will not do for permanent use. Locations should be chosen at convenient points, at stations or regular stopping places, not exceeding 20 miles apart—15 is better—and tanks of sufficient capacity put up. Tanks of from 20,000 to 30,000 gallons' capacity will answer where traffic is not very heavy, or even less would do, but small tanks are not advisable, as the supply is not as lasting, and in severe weather is more liable to freeze. The tanks should be erected upon a framework of posts of convenient height, so that the drop pipe will have a good sharp incline when water is being taken. For a tank of 20,000 gallons 12 posts 8″×8″ in size are sufficient; the foundation may be of stone or of piles capped with 8″×8″ for sills, the posts framed into them, and capped at right angles to the sills with 8″×8″ caps; on them rest the floor joists, and on the joists directly the bottom of the tank, the joists being cut away for the chime of the staves; a tank holding from 20,000 to 30,000 gallons, should be made of 3-inch staves and bottom. To make the tanks frost proof, all that is necessary is to put in a ceiling 18 inches below the top of the staves, and pack it with 18 inches of good sawdust, leaving the space between the top of the staves and roof, which should be perfectly tight, as a dead air space; also to pack it well around the supply, waste, and delivery pipes and under the floor; in extreme cold weather it will of course freeze a little, but not enough to do any damage. There are many different methods of supplying the tanks with water; that most in use is by a small steam pump; wind power is also quite extensively used and is considered quite economical, although

my experience has been that it lacks in that respect and is not altogether reliable. Hot air engines are also somewhat used, and I believe are considered economical and reliable. Our company have had one in use at Vassar for the last six or eight months, and are well pleased with its performance thus far. Too much care cannot be taken to have good water and a supply that is permanent. Soft water from streams is considered the best; water containing minerals, especially lime and other substances that coat boilers, should be avoided.

Station buildings come next in importance to water stations, if indeed any gradation in importance can be made; for successful and economical operating all are required. It may be supposed that, during the process of construction, the location has been chosen and the grounds secured. Usually, during the first excitement of the enterprise and the rivalry of the different centers or villages in their efforts to secure the road, a choice of location can usually be had, which should be made with reference to the convenience of access, and economy and convenience of laying out the sidings and arranging for the business of the company. It is well to secure ample room at first, for, after the grounds are once secured, it is strange how soon contiguous property appreciates in value, and often it is impossible to obtain more room without buying at exorbitant prices. The station building should be of sufficient size to accomodate the business of the place. In small places, where one man does all the work, I think it advisable to unite the passenger and freight buildings in one, as it is more economical as well as convenient. For places of only a hundred or two of population, where business interests are not very great, I have found a building 16×40 feet in size to be ample.

A convenient one is built as follows: 16×40, with 12 foot walls, the interior divided in the middle by an ordinary studded partition, making the freight room 16×20, and 16×20 for a waiting room and office; the office is made by running a lattice partition across from floor to ceiling, 6 feet from the end of the room. This lattice partition allows the waiting room stove to do duty for the office as well,—another item of economy, as you will please bear in mind that I am speaking especially of the equipment of a narrow gauge road, where cheapness and economy are a desideratum. In front of the office is a bay window, so that the agent or operator has full view of the track each way. In front of the building the platform should be not less than 12 feet wide; we build it 1 foot above the rail with a raised portion 8 feet wide in front of the freight room, and raise the freight room floor above the waiting room floor so as to be on a level with the floor of a box car; the platform across the end and rear of freight room is level with its floor and descends again to the level of the waiting room by an easy incline. For a place of several hundred inhabitants, we build a station 20×70 feet in size, similar to the former with the addition of a baggage room; and in large places make them 20×100 feet or more. Where two waiting rooms are needed we build the office partially between the two, so as to give convenient access to both. We have found the system of passengers and freight in the same building to work satisfactorily, having in no case, except at terminal stations, any other arrangement, although in very large places it would not be desirable. During construction the engines are usually left standing out of doors with no covering whatever; sometimes a rough temporary shed or engine house is built; but it now becomes necessary to have permanent buildings for them. Such are usually built in a partially circular form, with stalls or divisions to accomodate one engine each. A suitable location is chosen, and a turntable put up, and, radiating from it as a center, the tracks enter each division of the engine-house; underneath each track, inside the house, is built a pit for convenience in working at the under side of the machinery. These houses are usually built of either brick or stone, although cheapness of construction being often demanded, wooden ones may be built with simply a frame work of $8'' \times 8''$ posts, with $8'' \times 8''$ caps, $2'' \times 6''$ studding, $2'' \times 10''$ and $12''$ joists; they should be sheeted around the outside, then papered with heavy building paper, then boarded and battened. Double doors in front of each division may be built on a light frame of $2'' \times 4''$ in the same way; a tar and gravel roof will do as well as any. At terminal stations and points where engines are

kept for yard or other service a small building of sufficient size for the required service should be built, and may be located over an ordinary spur track in a convenient place. At headquarters, in connection with the engine or round-house (as it is usually called from its partially circular form), should be the repair and machine shops, the size, equipment, and capacity of which will depend on the number of engines to be kept in repair, and the amount of work to be done; the more complete they can be made as to machinery and appliances, the more economically can the work be done, although of course due regard must be had to the means to do with. It is also necessary to have car repair shops and a place for storage of coaches when not in use. A supply depot is almost a necessity on a road of any importance. It is also necessary that a road should be furnished with the necessary sidings at different points along its line, and yards at terminal and important points for the storage of cars, etc.

Cost.—I am aware that I am already making this article too long and am only touching upon a point here and there, so perhaps I had better close by giving an estimate of the various items of cost that are applicable to a narrow gauge road, as very little of what I have already said will not apply to any gauge of railroad. First the right of way must be secured, which, through a farming and timbered country, like the lower peninsula of Michigan for example, will cost from $20 to $50 per acre, although usually from one-half to three-quarters can be secured as a donation. However, we will say an average of $40 per acre, which gives, for a right of way 4 rods wide, 8 acres or $320 per mile. Clearing through the average country above alluded to can be done for $25 per acre, or $200 per mile, and grubbing will average perhaps $100 per mile, though in heavily timbered land it will cost very much more. A fair price for ordinary earthwork is 25 cents per yard, and at 5,000 yards per mile, (although on the P. H. & N. W. Ry., of over 200 miles, the average has been less than 4,000 yards per mile), we shall have for earthwork $1,250. Bridges, if not too expensive, may be figured $200 per mile and culverts at $100. This will give for right of way and road bed as follows:

Right of way	$320
Clearing	200
Grubbing	100
Earthwork	1,250
Bridges and culverts	300
Total	$2,170

Ties will cost, say 20 cents, although the average price paid for more than half a million ties used by the P. H. & N. W. Ry., has been but little more than 10 cents.

2,640 ties per mile at 20 c	$528.00
Rails, (steel) 35 lbs. per yard, 55 tons per mile, at $50 per ton	2,750.00
Fish plates, 532 pairs, weighing 8 lbs. per pair, at 3 c. lb	127.08
1,408 bolts, ½ lb. each, at 4 c	28.16
Spikes, 27 kegs per mile, 150 lbs. per keg, at 3 c. lb. (now considerably less)	121.50
Track laying per mile	200,00
Ballasting, 35 c. yard 1,100 yards per mile	385.00
Making per mile	$4,139.74
To which we must add about 5% minimum for siding, etc	206 98
Total per mile	$4,346.72

We will perhaps arrive at a better result for equipment by considering the amount needed for 100 miles of road. Let us say,

8 locomotives, from 14 to 20 tons @ $8,000 each	$64,000
6 first-class coaches @ $3,000 each	18,000
6 second-class coaches @ $2,300 each.	13,800
4 baggage and express cars @ $1,700 each	6,800
150 box cars @ $325	48,750
10 stock cars @ $350	3,500
50 flat cars @ $225	11,250
Hand-cars	900
Total for rolling stock	$167,000

or $1,670 per mile.

Water stations at terminal stations, and 4 intermediate on the 100 miles will cost $700 each	$4,200
For station buildings we will say 12—6 of the smaller size mentioned, which, with the platform and outbuildings complete will cost $600 each	3,600
Four, 20′×70′ in size @ $1,000 each	4,000
Two, 20′×100′ in size @ $1,300	2,600
Larger passenger and freight buildings at headquarters costing	15,000
Engine-house of 8 stalls at headquarters.	2,000
Small engine-house at other end of line.	500
Two turn-tables @ $600 each	1,200
Machine shops and machinery	10,000
Car repair shops	6,000
Coach house	1,000
Telegraph line	5,000
Total	$55,100

or $551 per mile. Making a summary as follows:

Right of way, road-bed, etc., per mile	$2,170.00
Ties, iron, track-laying, ballasting, etc.	4,346.72
Rolling stock equipment	1,670.00
Buildings	551.00
Fencing	600.00
Making a total per mile of	$9,337.72

to which may be added engineering and contingent expenses, which will make in round numbers at least $9,500 per mile.

ON THE ANTISEPTIC TREATMENT OF TIMBER.

By S. B. BOULTON, Assoc. Inst. C. E.

From "The Engineer."

The author commenced by referring to a paper by his late partner, Mr. H. P. Burt, Assoc. Inst. C. E., on the subject of timber preserving, which had been read at the Institution in 1853. Since that date the use of antiseptics for the treatment of timber had greatly increased. The process called creosoting, or the employment of the heavy oils of coal tar, had almost entirely displaced the other methods, whilst the manufactures connected with the residual products of gas making—from one of which residuals the creosote oils were derived—had experienced an enormous development. The author's connection, during thirty-four years, with this group of industries enabled him to offer the results of some personal experience and research, which he presented, together with those arrived at by other investigators. An historical description of the antiseptic treatment of timber was preceded by a few notes on the method pursued by the ancients for the preservation of wood and other perishable materials. The ancients were well acquainted with the manufacture and use of many kinds of oils, tars and bitumens, and frequently used them for the preparation of wood, with respect to which some notable instances were cited. The methods employed by the Egyptians in embalming their dead were dwelt upon at some length, and the author endeavored to elucidate some discrepancies in the descriptions of these processes, as recorded by Herodotus and Diodorus Siculus. The researches of Petigrew were alluded to, particularly his interesting experiment upon the heart of a mummy, which, after three thousand years' preservation, began immediately to putrify when the antiseptic substances were removed by maceration. This appeared to prove that no chemical transformation had taken place, but that the long immunity from decay had been the result of the abiding presence of the antiseptic. The growth of theories upon the causes of putrefaction was traced down to the commencement of the present century, reference being made to the "Phlogiston," and other exploded theories; also to the opinions of Macbride, Sir John Pringle, Sir Humphrey Davy, Thomas Wade, and others, and to their suggestions upon timber preserving. The progress of timber preserving during the railway era, and particularly between the years 1838 and 1853, was described, with especial reference to the competition between the four most successful of the processes. These four consisted in the employment of corrosive sublimate, sulphate of copper, chloride of zinc, and heavy oil of coal tar, which had been patented in England respectively by Mr. J. H. Kyan, Mr. J. J. Lloyd Margary, Sir William Burnett, and Mr. John Bethell. The distinction was pointed out between the real creosote—a product derived from the distillation of wood, but which had never been employed for injecting timber—and the so-called creosote which had been so successfully used for that purpose, the latter being a heavy oil produced from the distillation of gas tar. The theory that certain antiseptics preserved timber by coagulating the albumen, and by forming insoluble combinations with the woody fiber, had been advanced on behalf of all the four processes alluded to. But, in spite of some acknowledged success, the Kyanizing

Margaryizing, and Burnettizing systems were not found to be so durable in their effects as creosoting. Indeed, the salts of metals were gradually washed out of timber exposed to the action of water. On the other hand, the success of the creosoting process became completely established. In order to show the process of manufacture of the creosote oils, a short description was given of the ordinary methods of tar distilling. Coal tar, a black, viscous substance, was a residual product of gas making. It was split up by a preliminary process of distillation into three groups of substances, namely: (1) Oils lighter than water, containing the naphthas, benzoles, toluols, and other bodies, from some of which the aniline dyes were manufactured. This series of oils had never been used for timber preserving. (2) Oils heavier than water; the dead oils or creosote oils of the timber yards. These oils contained a great variety of different bodies, the properties of some of which were described, including carbolic acid, cresylic acid, naphthaline, anthracene, crysene, pyrene, quinolene, leucoline, acridine, cryptidine, &c. (3) Pitch, the residuum of the distillation. The creosote oils varied in their characteristics in different districts, according to the nature of the coal used in the gas works, and to the varying temperatures at which the coal was carbonized. The type of creosote called "London Oil," made from the tars derived from the coal of the Newcastle district, was contrasted with the so-called "Country Oil," typical of the product from the tar of the Midland and other coals. The former contains less of the carbolic and cresylic acids than the latter, but more of the semi-solid substance, which solidified within the pores of the timber, and more of the antiseptics which did not volatilize except at exceedingly elevated temperatures. The history of the controversy as to the respective merits of the two types of creosote oils was fully gone into. The carbolic and cresylic acids had been recognized as potent antiseptics; their presence appeared to arrest the action of all destructive germs, and the lighter and thinner country oils, which contained a comparatively large percentage of these tar acids, had therefore been preferred by many. The opinion of Dr. Letheby to that effect was recorded. On the other hand were cited the opinions and practice of the introducers of creosoting and of the earlier operators in that process, who used in preference the heavier types of creosote; and the early success of that creosote, both in England and in tropical countries, appeared to confirm their judgment. A number of experiments were then alluded to, stretching over a long series of years, and conducted by investigators in this and in other countries for the purpose of ascertaining which of the component portions of the creosote oils were the most durable and efficient agents in preserving timber. The result of these experiments appeared to show that it was not to the tar acids, but to the heavier and least volatile portion of the creosote, and to those bodies which solidified within the pores of the timber that the most durable results should be attributed. This apparent anomaly was explained by reference to numerous eminent authorities upon carbolic acid, who, whilst extolling its action as a most useful and powerful antiseptic for sanitary and surgical purposes, were in general agreement as to its possessing the following characteristics: That it was exceedingly volatile at ordinary temperatures, that it was readily soluble in water, and that its combinations with other bodies, including albumen, were not stable. It would, therefore, readily evaporate from timber exposed to the heat of the sun, especially in warm climates, and it would be washed out of timber in contact with water. The author's personal experience and experiments fully bore out the conclusion that the use of the heavier and least volatile portions of the creosote oils should be encouraged, and that from them the most durable results might be expected. Moreover, it was pointed out that recent investigators had discovered in these heavy oils, bodies which, if perhaps less potent, were more durable in their antiseptic effects than carbolic acid. By judicious selection and admixture, both London and country oils could be usefully employed. Shale oil and bone oil, however, and other oils lighter than water, should be excluded. The modern germ theory was discussed in its relation to timber preserving, and was believed by the author to be a more practical ex-

planation of the action of antiseptics upon wood than the older theories as to the coagulation of albumen and the formation of insoluble compounds. With respect to all bodies which had been extensively used for timber preserving their durable results appeared to be in an inverse ratio to their volatility in the atmosphere and their solubility in water. The germ theory constituted a severe but salutary test in choosing antiseptics for the treatment of wood. In the author's opinion the substances preferred should be not only germicides, but germ excluders, those being the best which were least soluble in water, least volatile in air, and most capable of becoming solid within the pores of the timber. A description followed of the various kinds of apparatus which had been in use during the present century for injecting timber with antiseptic liquids. The paper concluded with some remarks upon the subject of the hygrometric condition of timber at the time of injection, failures having repeatedly arisen owing to the timber being too wet at the time of creosoting. The author dwelt upon the importance of this subject, describing also his experience with various methods of getting rid of superfluous moisture artificially, and of a process which he had recently inaugurated, by which this result could be obtained in the creosoting cylinder itself, without injury to the timber.

The paper was illustrated by diagrams showing the most important products derived from coal, and the apparatus for coal tar distillation and timber preserving; also by tables, giving the properties of coal-tar products and other substances, of timber-preserving specifications, and of more than one hundred references to various authorities upon the topics alluded to in the paper.

THE MANUFACTURE OF CRUCIBLE CAST STEEL.

By HENRY SEEBOHM.

Transactions of Iron and Steel Institute.

The old-fashioned method of converting bar iron into steel, and afterwards melting it in clay pots to form ingots of cast steel, which are reheated and rolled or hammered to the size and shape required, has been so frequently described that I should not have ventured to bring the subject before the notice of the members of the Iron and Steel Institute had I not been requested to do so by the council of the society. It was suggested that, inasmuch as the *Journal* of the institute did not contain a paper on this subject, the occasion of the annual meeting of the members being held in the town of Sheffield, the headquarters of the crucible cast steel trade, would present an appropriate opportunity for collecting the facts connected with such an important branch of industry. These facts may perhaps be all the more interesting now that Sheffield has somewhat ungraciously failed to respond to the wishes of the institute; not in the least degree from want of hospitality, but from a deeply-seated belief that the Patent Laws are so bad that it is more profitable to keep secret a mechanical improvement than to patent it. Sheffield inventors have learnt by bitter experience that secrecy is the only protection for improvements; and if they think that they have found a goose that is going to lay golden eggs they lock and double lock the fowl-house door. It is said that there is no Act of Parliament through which you cannot drive a coach-and-four, and I am afraid that the Patent Laws are no exception to the rule, if you only have sufficient money to buy a strong enough team. I may premise that I have nothing new to bring forward. No Sheffield firm has yet succeeded in discovering the philosopher's stone. We all have our little secrets, which we jealously guard (and they have no greater scientific value than the secrets of the Masonic fraternity), but in spite of the important and valuable discoveries which have been perfected during the last quarter of a century in the methods of producing cast steel, the old-

fashioned crucible steel manufacturers of Sheffield still hold their own. They still convert bar iron into blister steel, and melt blister steel into cast steel, and some of them have not been altogether unsuccessful in transmuting cast steel into gold.

The accumulated experience of a century has convinced the manufacturers of crucible cast steel that the finest qualities can only be made from bar steel which has been converted from iron manufactured from Dannemora ore. This iron is expensive; its average cost for the last forty years has been at least £25 a ton; the process of converting it into steel is slow and costly; the process of melting in small crucibles is extravagant both in labor and in fuel, and consequently the best qualities of crucible cast steel can only be sold at a high price. So-called best crucible cast steel is sold at low prices by unscrupulous manufacturers, and bought by credulous consumers, but though it is quite possible for high-priced steel to be bad, it is absolutely impossible that low-priced steel can be good. The finest quality of steel cannot be made of cheap material or by a cheap process. Every year the attempt is made, and every year it signally fails. No one ever made a better try than Sir Henry Bessemer, but his failure was as complete as that of his predecessors. He attempted to produce an article at £6 a ton to compete with one at £60 a ton, and failed absolutely. It is true that his steel is a success, perhaps the most brilliant success of the century. I am not quite sure that he himself believes in his failure. In his lecture before the Cutlers' Company of London, in 1880, he chaffed the steel manufacturers of Sheffield on their antiquated attachment to the rule of thumb, and twitted them with the assertion that the high price of crucible cast steel arose from a combination of trade interest on their part and of prejudice on the part of their customers. Sir Henry Bessemer may have half ruined the wrought-iron trade, and revolutionized the pig-iron trade, but the crucible cast steel trade holds its own in spite of his great discoveries. When railways were first introduced, and wagons and coaches were to a large extent driven off the road many people thought that the price of horses would permanently fall, but exactly the contrary took place. Similar fears were entertained that the demand for crucible cast steel would seriously decline when Bessemer and Siemens steel came into the market. This has not been the case. The commoner qualities of crucible cast steel have been, to a large extent superseded by Bessemer and Siemens steel, but the enormous quantities made by the latter processes have required for their manipulation, directly or indirectly, such a large quantity of the better qualities of crucible cast steel, that the total amount of the latter now produced in various parts of the world is probably double that which was required before the birth of its rivals.

Chemical analysis plays a very important part in the manufacture of iron, Bessemer and Siemens steel, and even of the comparatively small quantity of crucible cast steel which is still used for purposes in connection with which it is not required to be hardened and tempered. It is possible to judge very accurately of the quality of those metals from their chemical analysis, almost as much so as from the results of mechanical tests, such as the breaking strain and the contraction of the area of fracture. But in what we may call, for want of a better name, the legitimate cast steel trade, chemical analysis, though it tells us a great deal, does not tell us everything. The analysis of steel shows the amount of other ingredients which it contains besides the nine-tenths or more of iron which forms its basis. The amount of carbon, silicon, manganese, sulphur, phosphorus, copper, &c., may be ascertained with tolerable accuracy, and the information thus obtained is often of the utmost importance; but it is quite possible to make a comparatively low-priced steel which shall show precisely the same chemical analysis as the best crucible cast steel; nevertheless it is found by practical experience to be inferior in quality. That this is a fact has been proved over and over again beyond all possibility of doubt. It is a sufficient reason why Sheffield manufacturers have been willing to pay such a high price for Dannemora iron for so many years; but it is not a sufficient reason why so many Sheffield manufacturers should ignore the results of chemical analysis altogether. Of every fact there must be

some explanation, though we may, for the present, at least, be ignorant of it. To say, with the Sheffield devotees of the rule of thumb, that the one steel possesses "body," and that the other does not, explains nothing, but merely adds to the synonomy of the subject by altering the nomenclature. If the metallurgical chemists could once convince themselves that this difference in quality is a fact, they would probably soon be able to give us an explanation. We already know much of the chemistry of steel, and what remains to be learnt is as certain to be some day discovered as the fact that Newton discovered the laws of gravitation. Mathematicians may never discover how to square a circle, mechanics will never discover a perpetual motion, nor will chemists ever discover the transmutation of metals; but the discovery of the chemical explanation of "body" is only a question of time. By way of stimulating enquiry I venture to suggest two possible causes of body which may be worth consideration as a tentative hypothesis of its nature. The best razor-steel contains one and a-half per cent. of carbon. It must be melted from evenly converted steel. It will not do to mix hard and soft steel together, or to melt it from pig "let down" with iron, though in either case the exact one and a-half per cent. of carbon may be the result. Steel made by the latter processes will not possess the requisite amount of body; consequently, the cutting edge of the razor will not stand. It must be melted from steel converted from iron made from ore containing manganese. It will not do to add the manganese in the form of spiegeleisen or ferro-manganese. Carbon and manganese exist in combination with iron not chemically combined in certain definite proportions, but as alloys, as mechanical mixtures in any proportion. We know that carbon exists in combination with iron in two forms, either as combined carbon or free carbon; is it not possible that manganese may also exist in two forms, and though the razor steel must have been boiled in the pot for half an hour after it was melted, to kill it and make the ingot pipe, is it not possible that the mechanical mixture of the carbon and the manganese is less homogeneous in steel made by the cheap processes than it is by that made by the old-fashioned method? It has been stated that the finest qualities of steel when hardened show a more perfect regularity in their crystallization when examined under a microscope than commoner qualities, and I venture to suggest that a possible explanation of "body" in steel may be absence of injurious ingredients, combined with the perfectly homogeneous presence of the advantageous ingredients. Hardened steel is crystallized steel; and perfect regularity of crystallization in steel which is required to be ground to a fine cutting edge may be a necessity which can only be secured by the slow and expensive old-fashioned method.

The principal reason why Bessemer and Siemens steel have failed so completely to supersede crucible cast steel for purposes where the better qualities are required, is that they cannot be made sound without the addition of silicon or manganese. In melting common steel (containing, for example, from 0.15 to 0.05 per cent. of phosphorus), the steel must be poured into the mould as soon after it has become perfectly fluid as possible, and as hot as the tensile strength of the pot will allow. In making the higher qualities of crucible cast steel (where the percentage of phosphorus ranges from 0.01 to 0.001) a similar mode of treatment would produce very strange results; the molten steel would boil over in the mould, the fracture of the ingot when cold would show a series of bubbles like a sponge, and its specific gravity would scarcely exceed that of wood. Some of these bubbles or honey-combs would weld up when the ingot came to be forged, but by far the greater number would be coated with an oxide, which would make a weld impossible, and the bar, if it was not burnt up in the fire, would be so full of the imperfections technically called "seams" or "roaks" as to be perfectly useless. To obviate this disastrous result it is necessary to boil the steel for nearly half an hour after it has become fluid, and then to allow it to cool down to a certain temperature before it is poured into the mould. This process is called, in the language of the votaries of the rule of thumb, "killing" the steel, and it is an axiom amongst them that the higher the quality of the steel the more "killing" it

takes. It is in this part of the process of crucible cast steel melting that its special virtue consists, and the cost and quality of the cast steel produced depend in a large degree upon the skill brought to bear upon it. There is an old proverb in Sheffield, usually expressed in the terse vernacular of the county, but which may be refined into the expression that if you put his Satanic Majesty into the crucible his Satanic Majesty will come out of the crucible. The converse of this is by no means the case. Though you may convert iron into steel in the crucible, you cannot convert bad steel into good steel in the crucible; but though you may put the most angelically pure steel into the pot, you may, by bad management, by not "killing" it properly, pervert it into satanically bad ingots. Now, this killing of the steel is precisely what cannot be done in the Bessemer or Siemens processes without the addition of such a large amount of manganese or silicon that the steel becomes brittle when hardened. I do not know whether chemists are agreed on an explanation of the necessity for "killing" high-class steel. When iron is made into steel in a converting furnace, it is assumed that the oxygen in the air in the converting pot unites with the charcoal, and is soon made into carbonic oxide, which is occluded by the white-hot iron, and forced by it to part with as much carbon as is sufficient to reduce it to carbonic acid. It has been ascertained that metals have the power of absorbing or occluding many times their own bulk of gas, and possibly the carbonic oxide, when it has parted with the amount of carbon necessary to reduce it to carbonic acid, is not then expelled from the iron, but may remain in an occluded state, and requires to be expelled in the melting pot by boiling. Be this as it may, it is a fact that if it be required to make blister steel harder than about 1.4 per cent. of carbon, it is necessary to convert it twice over, possibly in order that in the interval it may part with some of its occluded carbonic acid, so as to make room for a further occlusion of carbonic oxide.

Another fact which may throw some light upon this question is, that blister steel melted directly after being drawn from the converting furnace requires more "killing" than that which has been exposed to the air for some time, during which it has presumably had an opportunity of parting with some of its occluded gas. The addition of a portion of scrap steel materially assists the process of "killing," as would naturally be the case if we suppose that the scrap (which has been melted before) has parted with its occluded gas in the first melting. The fact that the presence of manganese or silicon helps largely to kill the steel may possibly be accounted for on the theory that the carbonic acid unites with the manganese or silicon, and becomes a solid, or it may be that in an alloy of iron with either manganese silicon or phosphorus, the occluded gas is expelled at a much higher temperature than in pure iron. Before describing the process of making crucible cast steel, it may be useful to devote a few words to the nomenclature of iron and steel. This is almost as much a vexed question as that of zoological nomenclature, and might form the subject of a code of laws, which would probably be as complete a failure as those issued under the auspices of the British Association for the Advancement of Science, which have made confusion in the scientific names of birds and beasts worse confounded. In Sheffield we attempt to discriminate between iron and steel, which we regard as generally distinct, and each of which we subdivide specifically, though it must be admitted that neither our generic nor specific names are very scientific.

Pig iron is melted direct from the ore in a blast furnace, and contains from 3 to 5 per cent. of carbon. When remelted it is called "cast iron," or "metal."

Spiegel iron is precisely the same, but contains in addition from 5 to 15 per cent. of manganese.

Bar iron, often called *wrought* iron, is pig iron which has been smelted and deprived of nearly all its carbon, either in a puddling furnace, or by the Walloon, Lancashire, or other analogous process; the spongy mass or ball of iron is usually hammered or rolled into a bar, which, for the Sheffield trade, is generally 3 inches wide $\frac{5}{8}$ inch thick, and from 6 to 12 feet long.

Puddled steel is precisely the same as "bar iron," except that the process of puddling is stopped when rather more than half of the carbon has been re-

moved from the pig iron. There is, consequently, no hard and fast line between bar iron and puddled steel, the one intergrading to the other by imperceptible degrees. Although there are an infinite number of intermediate stages between the softest bar iron and the hardest puddled steel, and although it is impossible to state the exact percentage of carbon which marks the dividing line between one and the other, it is usual to call all puddled bars which cannot be hardened in water, bar iron, and all those which can, puddled steel. This dividing line falls somewhere near a mixture containing a-half per cent. carbon, and although it looks very vague and unscientific to use two terms which thus intergrade, no confusion of any kind, or misunderstanding, has ever been known to arise from their use.

Blister steel is bar iron which has been converted into steel in a converting furnace, and varies in the amount of carbon which it contains from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. There are of course, an infinite number of degrees of carbonization between "hard heats" and "mild heats," but for the convenience of the trade six of them have been selected, and have received names as follows;

No. 1.	Spring heat.....	$\frac{1}{2}$	per cent. of carbon.
No. 2.	Country heat.....	$\frac{3}{4}$	" "
No. 3.	Single-shear heat.	1	" "
No. 4.	D'ble-shear heat.	1	" "
No. 5.	Steel-thr'gh heat.	$1\frac{1}{4}$	" "
No. 6.	Melting heat.....	$1\frac{1}{2}$	" "

Bar steel is blister steel which has been tilted or rolled down to the size required.

Single shear steel is produced by welding half a dozen bars of blister steel together. Only those bars are chosen in which the process of conversion has been so far carried on that the outside of the bar is steel, and the center of the bar iron. When these are welded together, and tilted or rolled down to a small dimension, the result produced is a mechanical mixture of iron and steel, a material which combines great tenacity with the capability of carrying a moderately hard cutting edge, and is much employed for certain kinds of knives.

Double-shear steel is produced by drawing down single shear to suitable sized bars and rewelding two of them together, so that the mixture of iron and steel may be more perfect.

Cast steel is steel that has been melted in a "pot" (called a crucible in the encyclopædias), and poured into a mould (called a "form" in the learned books), thus becoming an "ingot," which is afterwards hammered or rolled to the size required. It may be made of various "tempers," varying in the percentage of carbon which they contain from three-quarters or less to one and a-half or more. The different tempers may be arrived at in various ways. For the great majority of purposes there can be no doubt that the best way is to put into the melting pot broken pieces of blister steel converted exactly to the temper required; and the more evenly the steel is converted, and the more carefully all bars which are harder or softer than the temper required, or which are "flushed" or "aired," are rejected, the better. Blister steel, when carefully "taken up" or selected, will produce a cast steel which combines the greatest amount of hardness with the maximum amount of elasticity when hardened. It may, however, happen that for certain purposes "soundness" in the bar, the result of absence of honey-combs in the ingot, may be the most important quality required in the steel; for others, the property of welding most perfectly may be the *sine qua non*; or the great evil to be avoided may be the tendency to water-crack in hardening; or the steel may be used for some purpose where it does not require to be hardened, and the object to be secured is the combination of the greatest amount of hardness and toughness when unhardened. In all cases the mode of manufacture must be adapted to the objects which it is most important to secure. In addition to the mode of operations already mentioned, there are two other ways in which the same percentage of carbon may be secured. You may either put cut bar iron into the pot, and "fetch it up" to the required temper with charcoal, or you may put broken pig iron into the pot, and "let it down" to the required temper with cut bar iron. A fourth *modus operandi*, which, for most purposes is the best of all, might be enumerated, namely, the selection of blister steel slightly harder than the temper required, so as to admit of being slightly

let down to the exact temper by the addition of a small quantity of somewhat milder cast steel scrap.

Bessemer steel or *Siemens steel* do not require definition, nor do they come within the scope of this paper.

The process of converting, or, as it is generally called in the encyclopædias, the process of cementing iron into steel, is carried on in a converting furnace. This furnace consists of two stone troughs, technically called "converting pots," each of them about 4 feet wide, 4 feet deep, and 12 feet long, and placed side by side with a fire underneath them, the flues of which conduct the heat all around each pot. These troughs or pots are built up of slabs of a peculiar kind of firestone, obtained in the neighborhood of Sheffield, and possessing the property of not cracking if heated slowly to a high heat and allowed to cool slowly. The slabs are united together with a mortar made of ground fireclay. Over the two pots is built a vault of firebrick, and the whole is enclosed in a dome of red brick, to prevent as much as possible the heat from escaping. At the bottom of each pot is placed a layer of charcoal, broken up into small pieces, from a quarter to half an inch square. On this a layer of bars of iron is placed, which is covered with charcoal; another row of bars of iron follows, and so on until the pot is filled with alternate layers of charcoal and iron; it is then carefully closed with a thick cover of "wheel-swarf," a silicious species of mud which accumulates at the troughs of the Sheffield grinding wheels, and is, of course, the material of the grindstone, worn away in the process of grinding, and mixed with the finest steel dust which has been ground away, a substance which will resist long exposure to great heat, and renders the top of the pot practically air tight. In order to test the progress of conversion, and to ascertain the precise moment when the fire should be allowed to go out, two or three bars of iron are allowed to protrude through a hole in one of the pots made for the purpose. These bars, technically called "tap bars," are drawn and inspected at or near the close of the process, and are tightly packed in white ashes where they pass through the end of the converting pot, so that no air may find its way to the charcoal inside. The converting pots, full of alternate layers of iron and charcoal, and for all practical purposes hermetically sealed, are gradually raised to nearly a white heat, and kept at about that temperature for a week or more, according to the amount of carbonization required. Another week is occupied in the process of cooling, which must be done slowly, in order to prevent the pots from cracking, after which the cover is broken up and removed, and the bars, which went into the furnace bars of iron, are taken out of it bars of "blister steel," so called from the bubbles or blisters which have arisen on the surface during the process of conversion. Some of the charcoal has been consumed during the week at which it was white hot, but a considerable portion of it remains, and is taken out of the furnaces as black as it went in. A chemical change in the composition of the bars has taken place. They were originally pure iron, or nearly so, containing, perhaps, one-quarter per cent. of carbon, or less, were fibrous in their structure, and would bend double without breaking. After the process of conversion they have become a carburet or carbide of iron or steel, containing from half to one and a-half per cent. of carbon, according to the length of time they have been in the furnace and the degree of heat to which they have been subjected. They are now more or less crystalline in their structure, and can be broken by a slight blow of the hammer. The converting furnaces in use in Sheffield vary in size, some holding as much as thirty tons of iron, and others not more than fifteen tons. The iron gains slightly in weight by being converted into steel. The process occupies about three weeks, and a pair of pots may be used from twenty to forty times before they are worn out and have to be replaced by new ones.

As in every other process connected with the manufacture of steel, in the process of conversion it has to run the gauntlet of many perils. Sometimes the pots crack, air is admitted to the furnace, the charcoal is burnt, and in bad cases even the iron is oxidized. Bars which have thus missed conversion are technically said to be "aired," and even when very slightly affected may be easily discovered, in consequence of their having almost lost

the tendency to become rusty. If the furnace be raised to too high a heat the surface of the bars will melt, and when they are drawn it will appear "glazed." There are even instances handed down by tradition in Sheffield of unskillful convertors, who had heated the furnace under their care to such a degree that the whole mass of iron and charcoal had become fused together, and the end of the furnace had to be taken out to remove the contents. During the process of conversion the outside of the bar of iron is turned into steel the first, and in a spring heat the center of the bar remains iron, though when the bar is broken the crystals of iron have lost their brilliancy; in technical language, the bar is said to be full of "sap," though the sap is "killed," and no longer looks "raw" or "stares." In a country heat the sap is still more killed, and the crystals of steel on the edges have become more distinct. In a single-shear heat the fracture shows more steel on the outside, and less iron in the center, until, in a double-shear heat, the fracture shows about equal proportions of iron and steel. It is important that the transition from one to the other should be as gradual as possible. When the line of demarkation is violent or sudden, the process of conversion has been carried on too rapidly, and bars of blister steel so converted are said to be "flushed." In a steel through heat, as its name implies, all trace of iron in the fracture has been lost sight of, but the crystals of steel are small. A short time longer in the furnace will make the steel a melting heat; the crystals will be large, and in exceptional cases their facets will reach across the bar. The melting furnace consists of a row of oval melting holes, large enough to contain two melting pots, one in front of the other, and deep enough to allow of sufficient coke to cover the lids. From each melting hole a flue leads, in old-fashioned furnaces, into a flat stack, each hole having a separate flue in the stack, but many furnaces are now made with short flues from each hole leading into a main flue which ends in a single square chimney. The application of gas to the melting of steel has been successful, but for the highest qualities coke is principally used, as the control which the melter has over the temperature of each pot, which sometimes requires "keeping back" and sometimes "hurrying on," is supposed to be more absolute. There can be little doubt, however, that the adoption of gas melting furnaces is only a question of time. The furnace floor is on a level with the top of the melting holes; and the grate bars, as well as a flue leading into the chimney, by which the draft may be controlled, are accessible from the cellar. The pots in which the steel is melted are generally made in a room adjoining the melting furnace. They are composed of a mixture of Burton and Stannington clay, to which is sometimes added a proportion of Stourbridge clay, and, if the pots are required to stand a great heat, of China clay from Devonshire. A small quantity of ground coke, as well as of old pots ground, is also added. Great care is taken that the clay be absolutely disintegrated and perfectly mixed together. This is accomplished by treading it in a trough, the potmaker and his assistant kneading it with their bare feet. The pots are moulded in an iron "flask" by means of a wooden "plug," and are slowly dried at the back of the stack, and the night before they are used gradually heated to a dull red heat, a process called annealing. Pot-making is a very important part of the manufacture of best cast steel. It is absolutely impossible to make good cast steel if the pots are defective. Each pot lasts a single day, and is used three times, containing severally about 50, 44 and 38 lbs. of steel each round. The object of lessening the weight of each successive charge is to bring the surface of the molten metal to a different place in the pot, because the "flux," or scum, which accumulates on the surface has a chemical action on the silica of the pot, which is consequently decomposed for some depth just at that point, and the pot is reduced in thickness.

The bar steel is first carefully selected of the exact temper required, all flushed or aired bars are rejected, and after it has been broken up into small pieces and carefully weighed, it is conveyed to the pot, which has already been placed in the melting hole, through an iron funnel called a charger. The lid is carefully adjusted, and the melting hole filled with coke. The degree of heat to which the furnace is allowed to go is care-

fully regulated by the "puller-out," who is technically said to "work" the holes, and who has perfect control over them by means of the two flues, into either of which he can insert a firebrick if required; a brick in the melting hole flue lessens the heat by lessening the draft; one in the cellar flue increases the heat by increasing the draft. The head melter periodically inspects the pots, and gives the final instructions to the puller-out, and decides the precise moment when the steel is dead melted, and the holes sufficiently burnt down to allow of its being "teemed" or poured into the mould with a fair chance of producing a sound ingot. When the "puller-out" has put on his "clothes," by which is meant a series of sacking wraps which envelop the arms and legs, and are soaked with water to protect him from the heat, he raises the pot with a pair of "pulling-out tongs," and lifts it from the hole to the floor of the furnace. The lid is instantly taken off with a pair of lid tongs, and the scum or flux is removed by a skimmer from the surface of the molten steel, which is then poured into a cast-iron mould formed of two halves tightly ringed and wedged together. The interior of the mould has been previously "reeked" or covered with a coat of coal-tar soot, to prevent the ingot from adhering to it. The melting of the higher qualities of steel is a process requiring the greatest skill, and one of the principal reasons why the trade has become to such a remarkable extent localized in Sheffield, is the importance to this branch of the trade of being able to select from a large class of more or less experienced workmen, the few exceptional men in whom sound judgment, technical skill, and steady habits are combined. The chances of accident in the melting of steel are many and various. Not only badly made pots, but badly annealed or badly worked pots, are sure to "run," and the steel to be deposited amongst the ashes, where it imbibes so much sulphur as to be practically of no value. Should a piece of coke accidentally find its way into the pot, the ingot will show a bright sparkling fracture—technically speaking it will be said to "stare"—and under the hammer will prove "hot short," and crumble to pieces. If the steel be not long enough in the fire, it will teem fiery and produce a honeycombed ingot, and the same result will follow if it be too hot when it is poured. If it remain too long in the fire it will teem "dead," "the fracture of the ingot will look scorched," and though exceptionally sound, it will be brittle if hard, and wanting in tensile strength if mild. If the molten steel be chilled before it is poured into the mould, which may be detected by the stream skimming over as it is teemed, the fracture of the ingot will appear dull in color, and full of small holes or honeycombs.

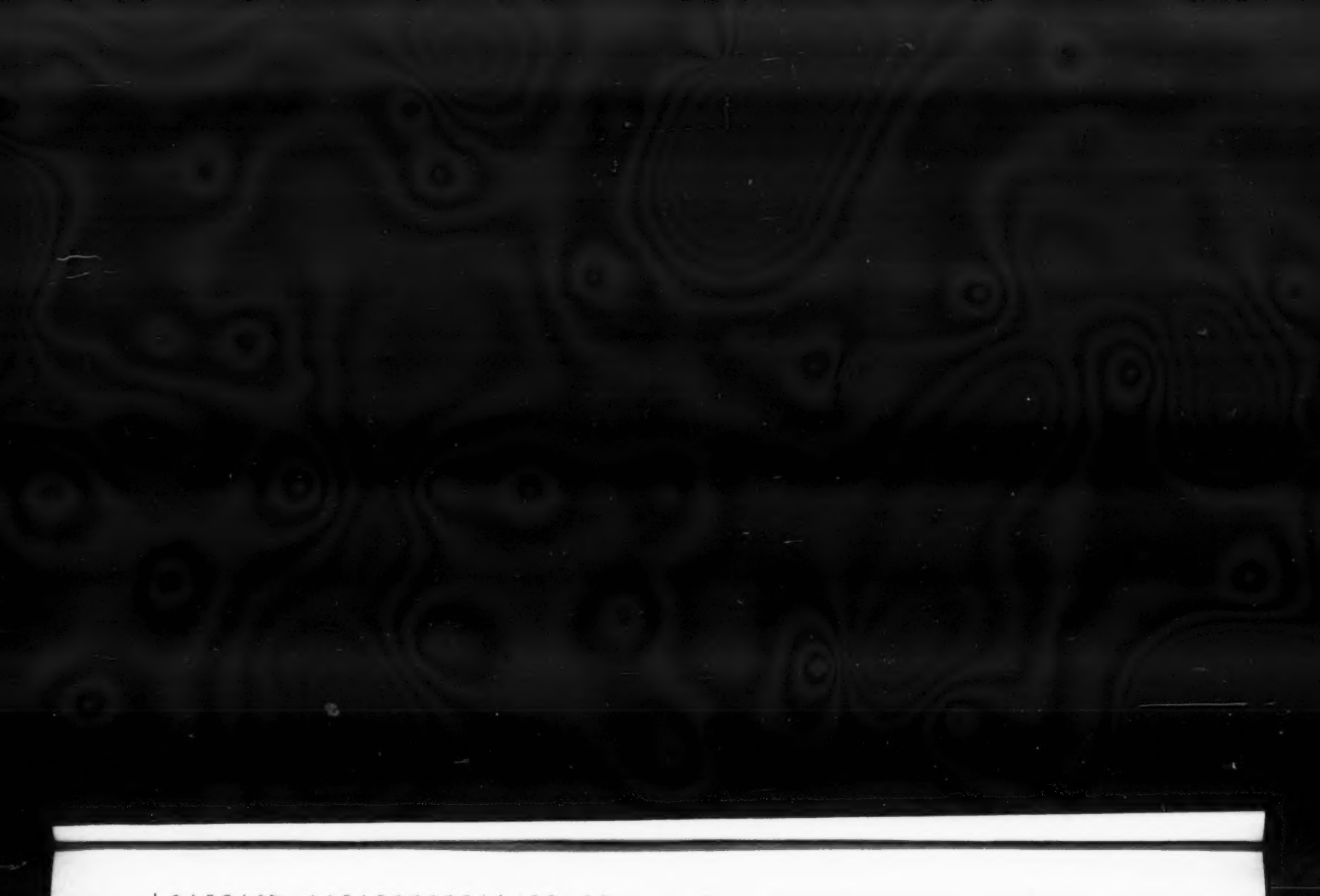
All ingots having a proportion of 1 per cent. or more of carbon, if properly melted with pipe, that is to say, the steel in the center of the ingot will settle down as it cools, leaving a hollow space in the middle at the top of the ingot to the depth of from 3 to 5 inches. When the ingot has become cold it must be topped, that is to say, the hollow part must be broken off, until the ingot shows a sound fracture, and before this fracture has had time to rust, the ingots must be carefully examined; the ingots which are not properly melted must be rejected, and the exact percentage of carbon which each ingot contains must be marked upon it. An experienced eye can judge of the percentage of carbon contained in an ingot to a wonderful nicety by the appearance of the fracture. Between 1 per cent. of carbon and 1½ per cent. every tenth per cent. is well marked, and an experienced hand will detect a difference between, for example, 1.3 and 1.35 per cent. In order to reduce the ingot of cast steel to the size and shape required by the consumer, it must be reheated, and, when hot enough, hammered or rolled to the dimensions ordered. Great care must be exercised in this process not to burn or overheat the steel; and, to prevent this, the half "cogged" bar must be continually turned round in the fire, and ground fireclay or sand and borax sprinkled upon it. In many cases it is necessary to give the surface of the bar, after it has been once drawn down under the hammer, a welding or "wash" heat, to close the small honeycombs which are scattered here and there on the surface of the ingot. It is a matter of great importance, especially with large ingots, that they should not be hammered until they are thoroughly heated or "soaked"

through, and it is of equal importance to all ingots that they should not lie too long "soaking" in the fire, especially in a dry fire, that is, one without blaze. The effect of hammering steel is to make it crystallize in very small crystals, a result which greatly improves its quality, but at the same time exposes it to the risk of various accidents in the process. The forging, tilting, and rolling of cast steel all require very experienced workmen, and a considerable outlay of expensive machinery. It is seldom that a workman attains exceptional skill in many departments, and great loss is sustained by too often changing faces or rolls, so that these processes cannot be satisfactorily or cheaply carried on upon a small scale, and this is one of the chief reasons why the crucible cast steel trade has to such a large extent become localized in a single town.

It might be supposed that when the best quality of iron had been selected, and the greatest care used in all the processes of manufacture—the converting, the melting, and the forging—the result must of necessity be good steel, and the troubles of the steel manufacturer would be over. But this is not the case by any means. So far from being over, the greatest difficulty has yet to be faced. The result may be good steel, but good steel only for certain purposes. There was a time, in the golden age of steel manufacturing, when steel was steel; and if it did not answer the purpose for which it was required, it was taken for granted that the fault lay with the workman. In some cases the manufacturer altered the percentage of carbon; but the "temper" of the steel was kept a profound secret from the consumer—in most cases, no doubt, because the manufacturer had very vague ideas on the subject himself. Chemical analysis was unknown in the trade; the despotic sway of the rule of thumb reigned supreme. Now it is customary for the manufacturer to take the customer into his confidence, and not only to inform him of the percentage of carbon which the steel contains, but also to give him the benefit of his opinion as to the purposes for which it is or is not suitable. Formerly, if the consumer discovered that chisel steel contained less carbon than tool steel, he owed his discovery entirely to his own wit. There can be no doubt that for many purposes a considerable latitude may be permitted, if the steel has the good fortune to fall into the hands of a clever workman who understands how to "humor" it, but next to quality—by which is meant percentage of phosphorus, sulphur, &c., combined with some other obscure points of crystallization—the most important thing is temper, or percentage of carbon. For some purposes, indeed, temper is of more importance than quality. Nothing is more common than for steel to be rejected as bad in quality, because it has been used for a purpose for which the temper was unsuitable. We may divide consumers of steel into three classes. First, those who use their own judgment of what percentage of carbon they require, and instruct the manufacturer to send them steel of a specified temper; second, those who leave the selection of the temper to the judgment of the manufacturer, and instruct him to send them steel for a specified purpose; and third, those who simply order steel of a specified size, leaving the manufacturer to guess for what purpose it is required. Fortunately, the size and shape generally furnish some clue to the purpose for which it is likely to be used. For example, oval steel is almost sure to be used for chisels, and small squares for turning tools, but 1¼ square may be used for a turning tool or a cold sett, or 1¼ round for a drill or a boiler cup, and the manufacturer has to puzzle his brain to discover whether the chances are in favor of its being used in the lathe room or in the blacksmith's shop. It cannot too often be reiterated of how much importance it is, when ordering steel, to state the purpose for which it is going to be used. Of course the number of tempers of steel is infinite, but the following is a list of the most useful:

Razor temper (1½ per cent. carbon).—This steel is so easily burnt by being over-heated that it can only be placed in the hands of a very skillful workman. When properly heated, it will do twice the work of ordinary tool steel for turning chilled rolls, &c.

Sawfile temper (1⅝ per cent. carbon).—This steel requires careful treatment; and although it will stand more fire than



razor-steel, should not be heated above a cherry-red.

Tool temper (1¼ per cent, carbon.)—The most useful temper for turning tools, drills, and planing-machine tools in the hands of ordinary workmen. It is possible to weld cast steel of this temper, but only with the greatest care and skill.

Spindle temper (1⅛ per cent. carbon).—A very useful temper for circular cutters, very large turning tools, taps, screwing dies, &c. This temper requires considerable care in welding.

Chisel temper (1 per cent. carbon).—An extremely useful temper, combining as it does great toughness in the unhardened state, with the capacity of hardening at a low heat. It is consequently well adapted for tools when the unhardened part is required to stand the blow of a hammer without snipping, but where a hard cutting edge is required, such as cold chisels, hot setts, &c.

Sett temper (⅞ per cent. carbon).—This temper is adapted for tools where the chief punishment is on the unhardened part, such as cold setts, which have to stand the blows of a very heavy hammer.

Die temper (¾ per cent. carbon).—The most suitable temper for tools where the surface only is required to be hard, and where the capacity to withstand great pressure is of importance, such as stamping or pressing dies, boiler cups, &c. Both the last two tempers may be easily welded by a mechanic accustomed to weld cast steel.

It is a somewhat remarkable fact that although steel is intermediate in chemical composition between wrought iron and cast iron, containing more carbon than the one and less than the other, its properties are quite different from either of them. It may be made to resemble either of them alternately, but it is principally used in a third condition, in its capacity to assume which the great value of steel consists. Annealed steel has nearly all the properties of lead, being very soft and malleable. Hardened steel has nearly all the properties of glass, being very hard and brittle. Tempered steel has most of the properties of whalebone, being hard but at the same time elastic. The chemical change which takes place during these processes has not yet been discovered. We might evolve a very pretty theory to account for it, by assuming that in the process of annealing some of the combined carbon was liberated, and existed in the steel in the form of free or uncombined carbon; but such a theory only explains part of the facts, and is not, I am afraid, borne out by the results of chemical analysis, so that we must fall back upon the mysterious and unknown laws of crystalization. The effect cannot be due simply to the increased density of the hardened steel caused by the contraction of the steel by sudden cooling. It is a remarkable fact that the specific gravity of hardened steel is less than that of unhardened steel. Steel, of course, expands with heat, and when it is allowed to cool slowly regains its original size; but if it be cooled suddenly, the only known way in which it can be hardened, although it contracts very much, it does not quite reach the small size of the unhardened state. However complicated the details of the manufacture of cast steel may be the complications involved in its subsequent use are still greater. It would be impossible to lay down exact rules for each of the thousand and one tools in which steel is used. The treatment of each tool in each process which it undergoes is an art that can only be learnt by practice, and can no more be taught in a book than the arts of skating, riding, or swimming. The utmost that can be done is to lay down certain general rules, which may explain to some extent, if they fail to teach, the most important details of manipulation. All steel may be regarded as involving a question of compromise. Each tool requires a certain degree of hardness; the problem is how to secure the maximum amount of toughness that is compatible with it. To secure this, the first step that must be taken in bringing the steel into the shape required is to heat the steel as little as may be before it is forged, and in the process of forging to hammer it as much as possible. The worst fault that can be committed is to heat the steel more than is necessary. When steel is heated it becomes coarse-grained; its silky texture is lost, and can only be restored by hammering or sudden cooling. If the temperature be raised above a certain point, the steel becomes what is technically called "burnt."

and the amount of hammering which it would require to restore its fine grain would reduce it to a size too small for the required tool, and the steel must be condemned as spoilt. Overheating in the fire is also the primary cause of cracking in the water. One of the principal reasons why a high quality of steel is required for certain purposes is, that it will suffer less injury by being heated to a greater degree, or by being heated and reheated a greater number of times, than inferior qualities of steel. In heating steel the happy medium must be attained between heating it too much or too little, and between letting it lie too long "soaking" in the fire and not "soaking" it through. Both the degree of temperature and the duration of the heat must be carefully watched. Some tools, such as circular cutters, files, &c., after they are forged into the shape required, must have teeth cut into them. Before this can be successfully accomplished a preliminary process has to be gone through. The process of hammering or forging the steel into the shape required has hardened it to such an extent as to make the cutting of teeth into it impossible or difficult, and it must consequently be annealed. This process consists in reheating the steel as carefully as before, and afterwards allowing it to cool as slowly as possible. Many tools are only required to be hardened on a small part of their surface, and it is important that the unhardened parts should possess the maximum amount of toughness, the minimum amount of brittleness that can be attained. The process of annealing, or slow-cooling, leaves the steel coarse-grained, gives it its maximum of ductility, and causes it, in fact, to approach in its properties those of lead.

The last process in the manufacture of articles made of steel, where the invaluable property which distinguishes steel from wrought iron or cast metal is revealed, is the double process of hardening and tempering, by which we suddenly change the steel from lead into glass, and afterwards gently change the glass into whalebone. In these as in all other processes which steel has to undergo, it has again to run the gauntlet of fire. It does so, however, at much greater risk than heretofore. The forging of the tool is finished; it has taken the final shape to which it was destined; and any injury which may be done to it by overheating is irrevocable, and can no longer be cured or mitigated by the hammer. It is necessary, therefore, to double and redouble the care bestowed upon the heating of the steel, lest the temperature be raised beyond the point necessary to secure the required hardness. The part of the steel required to be hardened must be heated through and heated evenly, but must on no account be overheated. The tool must be finished at one blow, the blow caused by the sudden contraction of the steel produced by its sudden cooling in the water, and if this blow be not sufficient to give to the steel a fine grain and a silky texture, if after the blow is given the fracture (were the tool broken in the hardened part) would show a coarse grain and dull color instead of a fine grain and glossy luster, the tool is spoiled, the labor bestowed upon it is thrown away, and it must be consigned to the limbo of "wasters." The special dangers to be avoided in hardening each kind of tool must be learned by experience. Some tools will warp, or "skeller," as we say in Yorkshire, if they are not plunged into the water in a certain way. Tools of one shape must cut the water like a knife; those of another shape must stab it like a dagger. Some tools must be hardened in a saturated solution of salt, the older the better; whilst others are best hardened under a stream of running water. Most tools have a tendency to water-crack if taken out of the water before they are absolutely cold. Where the edge of a tool only is hardened care should be taken to move it up and down in the water, so as continually to change the water level lest the tool should crack at the water level. Steel contracts in hardening, and contracts differently where it is cooled suddenly from the places where it is cooled slowly. If the hardened part joins the unhardened part too suddenly, the steel at the junction will be in a dangerous condition of tension, which predisposes it to crack, and it is wise to lessen the amount of tension by distributing it over as great an area as possible. In some tools, where the shape necessitates a great difference in the rapidity of the cooling of the various parts, it is often wise to drill holes in the thicker parts, where they will not inter-

fere with the use of the tool—holes which are made neither for use nor ornament, but solely with a view of equalizing the rapidity of the cooling of the various parts, so as to distribute the area of tension, and thus lessen the risk of cracking in hardening. So many causes may produce water-cracks, that it is often difficult to point out the precise cause in any given case. The most common cause is the overheating of the steel in one or other of the various processes through which it has to pass. A second cause may be found in the over-melting or too long boiling of the steel, causing it to part with too much of its occluded carbonic acid, a fault which may be attributed to the anxiety of the manufacturer to escape honeycombs in the ingot. A third cause may sometimes be discovered in the addition of too much manganese, added with the same motive. A fourth cause may, curiously enough, prove to be a deficiency of carbon, one of the most common causes of water-cracking in files; whilst in some cases too much carbon will produce the same effect. A fifth cause may be one which, as a steel manufacturer, I ought to mention in a whisper—the presence of phosphorus in the steel; but, after all, this may not be the fault of a too greedy manufacturer, who wants to make too much profit; it may possibly be the fault of a too stingy consumer, who will not pay a price sufficient to admit of a good quality of iron being used. There is nothing so dear as cheap steel. It must be more economical to put five shillings' worth of labor upon steel that costs a shilling, to produce a tool that will last a week, than to put the same value of labor upon steel that costs only ninepence, to produce a tool that will only last a day. The system adopted by some large consumers of buying best tool steel by tender, is one which in too many cases defeats the object for which it was instituted, and by lessening the price, and consequently deteriorating the quality, causes the steel bill to be apparently lessened at the cost of the labor bill, so that extravagance instead of economy is the result. In fact, it is an illustration of the proverb about being "penny wise and pound foolish." Scores of firms in the steel trade habitually offer best cast steel at prices varying from forty to forty-five pounds a ton. The statement that the steel supplied is the best that can be made may be accurately described by an ugly little word of three letters, and the firms which make it are liable to be suspected of "voluntary inaccuracy."

The culminating point in the manufacture of tools made from steel, the final process which gives to them their most valuable properties—properties possessed by no other metallic substance—is that of tempering. The steel was originally lead; the process of hardening has turned it into glass; but we do not want glass—it is too brittle; we want whalebone. An unhardened knife would bend like wrought iron; a knife hardened only would break like cast metal. We want the elasticity of the whalebone. Our knife must spring like—like what?—like *steel*. To attain this quality it must be tempered. If a piece of hardened steel be heated slightly and then allowed to cool, it becomes tempered. It suddenly changes from glass to whalebone, and in the process of changing its nature it fortunately changes its color, so that the workman can judge by the color which it has assumed the extent of the elasticity which it has acquired, and can then give to each tool the particular degree of temper which is most adapted to its special purpose. The various colors through which tempered steel successively passes are as follows—straw, gold, chocolate, purple, violet and blue. Of course in passing from one color to another, the steel passes through the intermediate colors. It really passes through an infinite series of colors, of which the six above mentioned are arbitrarily selected as convenient stages. It must be borne in mind that the elasticity of tempered steel is acquired at the expense of its hardness. It is supposed that the maximum of elasticity and hardness combined is obtained by tempering down to a straw color. In tempering steel, regard must be had to the quality most essential in the special tool to be tempered. For example, a turning tool is required to be very hard, and is generally taken hot enough out of the water to temper itself down to a degree so slight that no perceptible color is apparent; whilst a spring is required to be very elastic, and may be tempered down to a blue. Hardening in oil is a mode of treating

steel which is of special value for certain tools, and appears, to a certain extent, to attain by one process the change from lead into whalebone without the passage through the intermediate glass stage. It is unfortunately not yet possible to give any scientific explanation of the change which takes place in the hardening and tempering of steel. All that chemists can yet do is to mystify their readers by writing unintelligibly about molecular rearrangement and crystalline transformation.

In speaking of the various foreign substances which are found in cast steel, I have confined myself, for the most part, to those which are supposed to be injurious to its quality; but before I close my paper, a word or two must be said upon the various materials which are added to cast steel with the intention of improving it. If the steel manufacturers of Sheffield are not doctors of chemistry, they most of them practice as quacks. It has ever been a darling dream of the Sheffield steel melter to discover some substance—some philosopher's stone—which will transmute common cast steel into best cast steel. The various substances used in the melting of cast steel, and supposed to have a chemical effect upon the material melted, are known by the technical name of "physic." The most universally used of these is peroxide of manganese, mixed with a little ground charcoal. Common salt, rock salt, salammoniac, chromate of potash, prussiate of potash, and even ground fluor spar and broken glass, form ingredients of the physic used by some steel melters. Manganese, either in the form of spiegeleisen, or of ferro-manganese, is also largely used, and has a definite effect upon the steel, it prevents, to a large extent, the formation of honeycombs in the ingot, and increases the welding capacity of the steel; it gives the steel a greater tenacity when hot, so that it may be heated to a greater heat without cracking under the blow of the hammer or the tension of the rolls; but it must be very cautiously used, as it undoubtedly increases the brittleness of the steel, and its tendency to water-crack, if it be added in the melting pot, instead of being previously suffused through the iron. Silicon is even more dangerous; it causes the steel to crystallize in smaller crystals; it materially assists its capacity to receive a high polish; it increases its soundness, but makes it more brittle. Wolfram, or tungsten, added in the form of a metallic alloy, is used to a considerable extent in the manufacture of a special steel, sometimes called Musbet steel, which is frequently made so hard that it does not require to be hardened. It is used principally for turning tools, which, in consequence of the temper of the steel not being liable to injury by heat, can be driven at a higher speed than usual. Special steel of this kind is the finest grained that can be produced, but is so brittle that it can only be used by exceptionally skilled workmen. Chromium is sometimes used instead of wolfram, and it is said that titanium is also employed, but I am not aware that any of the latter metal has yet been detected in steel by chemical analysis. A special steel for taps, called mild-centered cast steel, is made by converting a cogged ingot of mild cast steel so that the additional carbon only penetrates a short distance. These bars are afterwards hammered or rolled down to the size required, and have the advantage of possessing a hard surface without losing the toughness of the mild center.

It is much to be regretted that no easy method of testing cast steel has been invented. The amount of breaking strain, and the extent of the contractions of the area of fracture, give valuable information respecting iron or steel which is not hardened, and is not required to be used in a hardened state, but for hardened and tempered steel they are practically useless. It is very difficult to harden and temper two pieces of steel to exactly the same degree. A single test is of comparatively small value, as a second-rate quality of steel may stand very well the first time that it is hardened, but deteriorates much more rapidly every time it is rehardened than is the case with steel of a high quality. Nor is the breaking strain a fair test of the quality of cast steel. For many tools the capacity to withstand a high amount of breaking strain, slowly applied, is not so much required as its capacity to withstand a sudden shock. The appearance of the fracture of cast steel is also very illusory. The fineness of the grain and the silkiness of the gloss are very capti-

vating to the eye, but can be produced by hammering the bar until it is almost cold.

The consumer of steel may be enraptured, if he be of a poetical turn of mind, by the superb fracture of a bar of steel, reminding him of a picture by Ruskin of the aiguille structure of the higher Alps. But, after all, this is only a dodge, depending upon the inclination of the axis of the revolving hammer to the plane of the anvil. The practical consumer of steel must descend from the heights of art and science and take refuge in the commonplace of the rule of thumb, and buy the steel which he finds by experience to be full of "nature" and "body." If I have been successful in my attempt to explain the art and mystery of crucible cast steel making, you will have understood that the converting, melting and forging of steel are three arts, each of which requires as much dexterity as the arts of skating, riding or swimming. To arrive at perfection in these arts is difficult to those who do not inherit from skilled ancestors the facility to learn them; hence the trade has become localized in a few centers, of which Sheffield is the oldest and by far the most important. The arts of forging, hardening and tempering, which are necessary for the further manipulation of the steel after it leaves the hands of the manufacturer in Sheffield require equal dexterity, so that the art of steel-making, if not mysterious, is very complicated. The real mystery lies in the chemical explanation of the effects produced, and when chemists have explained the phenomena of hardening and tempering steel, they may possibly discover why cast steel made from Dannemora iron is superior to the imitations of it. At present I presume that the candid chemist must admit that there are more things in best crucible cast steel than are dreamt of in his philosophy.

THE CAUSES AND REMEDIES OF CORROSION IN MARINE BOILERS.

By J. HARRY HALLETT.

From "Iron."

Marine engineers are all striving in various ways to attain increased economy of fuel in steamers. Among other means of doing so, triple-expansion engines of high initial pressure are being introduced, which appear to be gaining much favor, and will no doubt in time supersede the ordinary two-cylinder type. The increased pressure of steam evidently renders it necessary to be still more guarded than hitherto as to the deterioration of boilers. Steel boilers are now in very general use, and there can be no doubt as to their efficiency; but the writer's experience is that they are equally liable with iron boilers to corrosive influences. On careful scrutiny he has found in steel plates severe corrosion concealed by a very slight scale, upon the removal of which the plate has proved to be covered with a black substance, probably a black oxide of iron. In many cases a casual inspection may fail to detect this. Internal corrosion is well known to be most erratic in its action; it attacks the metal in different parts of the boiler, in different ways, and from various causes. The principal sources of corrosion, however, may be discussed under the two heads of defective design and defective management: which is equivalent to saying that an ordinary marine boiler will hardly be subject to corrosion at all, if well designed and well managed.

Design.—The most frequent fault of design which bears upon corrosion is the want of sufficient space for allowing a thorough examination to be made of every part of the boiler. The tubes are often placed so far out in the wings that it is impossible to get down to look at the sides of the furnaces, or so close to the furnace crowns that there is no room to get over these. It would be preferable to allow at least nine inches between each furnace crown and the bottom row of

tubes, especially as this row is not useful as heating surface when placed so close down to the crown. The manholes are often inconveniently placed and made too small, which always affords an excuse for want of proper attention on the part of the men in charge. Manholes should always be fitted in the wings if the size of boiler will allow. There can be no doubt that the best way to prolong the life of a boiler is to watch it carefully and constantly, so as to note the commencement of deterioration and take steps to check it. In any part which cannot be seen, it is impossible to know what is going on. Another fault of design, which easily escapes notice until too late, is the pitching of the steam-space stays, so that one or perhaps several of them come over a space, instead of over a tube, thus rendering the effective use of the scaling tool very difficult, or even impossible in that particular vertical space. With the object of securing the conventional 20 square feet of heating surface per horse-power, the tubes are sometimes too closely pitched, which causes bad circulation, besides rendering the spaces liable to become soon choked with scale. The tubes should never be less than $1\frac{1}{4}$ inch apart, both vertically and horizontally.

MANAGEMENT.—The first point to be looked to in the management of a boiler is the circulation. In an ordinary multibular marine boiler the circulation takes place by the water ascending from the furnace crowns, and from the sides, backs, and fronts of the combustion chambers, and descending at the wings; the tubes do, of course, somewhat obstruct the upward current. There can be no doubt that the coolest places in the boiler are those where the circulation is most defective, as is naturally the case below the level of the fire-bars. The water in this part of the boiler always contains the greatest percentage of solid matter, and here the greatest deterioration may, therefore, be expected to be found. Double-ended boilers are not only subject to the same corrosive action as single-ended ones, but being longer they are also more prone to suffer from racking strains, due to the difference of temperature between their upper and lower parts. One method of reducing this difference as far as possible, is to fit the internal feed-pipe so that it is led along on a level with the upper tubes, so as first to warm the water inside it, and is thence carried down so as to discharge the warmed water in a horizontal direction at the bottom of the boiler. The scum pipe should be fitted with a pan, shaped like an inverted saucer, and placed just above the level of the water for the scum to collect under it; and it should always be blown off upon raising steam, and also about once a day when under weigh. The blow-off cock should either be attached at the bottom of the boiler, or else an internal pipe should be fitted to it, reaching down to the very bottom. Salt is not deposited until the density of the water exceeds 4-32ds by the salinometer, that is, until there is more than 4 lbs. of salt in 32 lbs. of water; beyond this proportion the deposition of salt then begins upon the furnace crowns, &c. It is recommended that the opportunities occurring from time to time by the engines being stopped should be taken advantage of for pumping up the boiler to the top of the gauge glass, and then blowing it down to the bottom of the glass. This, repeated about twice or thrice on each occasion, will work wonders. The great usefulness of this plan arises from the fact that while the engines are stopped there is little or no steam being made, and therefore no solid matter is being deposited from the water; so that the extra feed-water pumped in at that time does much more to freshen the boiler than it would if the engines were at work. When in charge of the engines of a steamer on a voyage from England to Rangoon, calling at several ports on the way, and thence to Venice, the writer kept water in the boilers continuously during the whole round; that is to say the boilers were never entirely run out and refilled, but were blown down from time to time as above described. They were under steam about seventy-two days, and upon being opened out at the end of that time had only a slight scale upon them of uniform thickness, and no indication of pitting or corrosion.

The mode of treatment adopted by the writer for new boilers is to have them well washed out before filling, then to run them up, and when they are filled with water up to the normal height, to throw into each through the top manhole about a bucketful of common soda. When steam is raised to about 30 lbs. per square

inch, blow out a little through the scum cock. Before adding any more water, start the feed donkey, and let it deliver for sometime over the side of the ship, so as to get rid of any dirt, &c., in the pump; this is a very useful precaution to observe whenever the feed donkey is employed. After starting the main engines, let them run at first with the feed water overflowing from the hot well into the bilges; this will clear the condenser. When under weigh, it is advisable to use the blow-down cocks sparingly. The appearance of the water in the gauge glass shows at a glance the state of the water in the boiler; if the glass is at all dirty inside, that is proof positive of the water not being clean enough; and this can be cured by the use of the scum cock. In a double-ended boiler a scum pipe should be fitted at each end. The scum pipes are sometimes so fitted that their position can be altered to suit the trim of the ship, which is a point of far more importance than is generally imagined. After a run, when steam is finished with, the water should be blown out from the bottom and the boilers then kept thoroughly dry. Before refilling they should be carefully swept down inside, and washed out. There is no doubt that one of the most active causes of deterioration in boilers is the want of proper care in their treatment. Cases have come under the author's notice of boilers being blown down as far only as the level of the bottom manholes, and refilled, without care being taken to draw the water out of the bottoms. This process having been frequently repeated, the water at the bottoms became so impregnated that the heads of the rivets and the lower half of the compensating rings round the manholes were corroded away, while the other parts of the boilers were in good condition. Many good boilers are ruined through careless management, and the makers are wrongly charged with allowing their work to come from the shop not properly finished. Another example, out of numerous cases met with, is that of a pair of boilers which were fitted some little time ago with hydro-kineters, or internal steam-jet nozzles for stimulating the circulation of the water in the cooler places below the furnace flues. Upon a recent examination the valves of these appliances were found to be hard and fast, in consequence of carelessness in supervision. Another great evil is raising steam too quickly, and blowing out under too great a pressure, which cannot be too strongly condemned. Corrosion in the upper parts of the boiler is principally caused by the introduction of oil, tallow, and other greasy substances from the engines. In all the steamers with which the writer is connected he has discarded the use of all oil or other lubricant in the cylinders, with the most satisfactory results.

Various remedies have been suggested for preventing corrosion; among others, air-extractors and circulating tubes. Zinc has been tried, both cast and rolled, and some engineers report favorably on its use; but to make it effective, very large quantities must be used, as it so quickly oxidizes, and thus loses its protective qualities. The electrogen of Mr. Hannay's invention, which is rapidly gaining favor, is a very simple little appliance, and, as far as the writer has experimented with it, is very effective. The principle upon which it works is the setting up of a small galvanic battery in the boiler, by mans of a ball of zinc cast upon a copper bar, and then hammered, to make it more impervious to the action of the water; on each end of the copper bar a wire is soldered, and the two wires are again soldered to different parts of the boiler, so as to obtain metallic contact. Boilers which had shown a tendency to corrosion looked quite healthy in a very short time after these appliances had been fitted to them. Marine boilers are not troubled with much external corrosion, especially modern boilers, because much more care is now taken in fitting them into the ships than was formerly the case. They are now properly coated, and are not fitted too close down to the bottom of the ship, plenty of room being allowed for access to the seams. But that all the mischief to be contended with is not confined to the waterside of the boiler is shown by the following incident. Some four and a half years ago the writer was called in to survey a boiler that had exploded and killed the chief engineer and firemen. Upon examination it was found that the bridges had been built up close to the backs of the combustion chambers; the dirt, &c., had been allowed to accumulate for some time, and corrosion had been going on upon both sides of the plate without be-

ing noticed. After the accident, when all had been cleared away, the iron was found to have oxidized so much that in some parts it was barely 1-16th of an inch thick; hence the explosion. The backs had been so built up for the express purpose of economising fuel; but experience goes to prove that this is a fallacy, and many cases could be mentioned where similar bridges have been taken out without making any difference in consumption of fuel, except that, if anything. the economy had been in favor of their absence. There is nothing like cleanliness to prolong the life of a boiler. When a vessel is to be laid up, a good plan is to pump the boiler full up to the very top of the dome, and keep it so until it is again required. Another method of preserving a boiler not in use is to empty it and clean it thoroughly, then close all the manhole doors except one at the bottom, put in a small stove full of burning coke, and close up the bottom door quickly. The object of both these methods is, of course, to exclude air as thoroughly as possible.

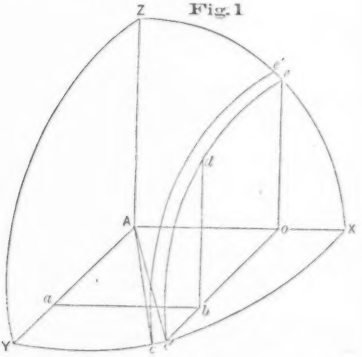
GENERAL DISCUSSION OF WIND PRESSURE UPON SPHERICAL, CYLINDRICAL, AND CONICAL SURFACES.

By P. H. PHILBRICK.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

Let XYZA represent one fourth of the windward half of a spherical dome; XA the direction of the wind, inclined to the horizon at angle a; cde and $c'e'$ two arcs near together in planes parallel to YAZ, and O the center of cde.

Fig. 1



$OAc = i$ $cAc' = di$, r = radius of the dome.

Let P equal the pressure upon a unit of plane surface normal to the direction of the wind; N = the normal pressure upon any surface; X, Y, Z, the x, y and z components of the pressure.

We have, $co = r \sin. i$, $cde = \frac{\pi}{2} r \sin. i$, $cc' = r di$;

$\therefore$ the area of the band

$$cde\, c'e' = \frac{\pi}{2} r^2 \sin. i\, di. \quad (1)$$

According to Duchemin (see "Annals of Mathematics," vol. 1, No. 2, p. 47) the pressure upon a unit area of surface is $\frac{P}{1+\frac{1}{2}\tan.^2 i}$, i being the angle of incidence. Hence the pressure on the band is

$$dN = \frac{P}{1+\frac{1}{2}\tan.^2 i} \frac{\pi}{2} r^2 \sin. i\, di =$$

$$= P\pi r^2 \frac{\sin. i\, di}{2+\tan.^2 i} \quad . \quad . \quad (2)$$

$$= P\pi r^2 \frac{\cos.^2 i \sin. i\, di}{1+\cos.^2 i} =$$

$$P\pi r^2 \left(\frac{d \cos. i}{1+\cos.^2 i} - d \cos. i \right) \quad (3)$$

$$\therefore N = P\pi r^2 \int \left(\frac{d \cos. i}{1+\cos.^2 i} - d \cos. i \right) -$$

$$= P\pi r^2 \left\{ \tan. \overset{-1}{\cos.} i - \cos. i \right\}_0^{\frac{\pi}{2}} \quad . \quad (4)$$

$$= P\pi r^2 \left(1 - \frac{\pi}{4}\right) = .4292\, P \times \tfrac{1}{2}\pi r^2 =$$

$$= .6742 P r^2. \quad . \quad . \quad (5)$$

On the dome the pressure is

$$4N = .4292\, P \times 2\pi r^2 = 1.3484\, P r^2. \quad . \quad (6)$$

The average normal pressure is, therefore equal to $.4292\, P = \left(2 - \frac{\pi}{2}\right) P$.

To find X. We have, $dX = dN \cos. i$; $\therefore$ from (4),

$$X = P\pi r^2 \int \left(\frac{\cos. i d \cos. i}{1+\cos.^2 i} - \cos. i \, d \cos. i \right)$$

$$= \tfrac{1}{2} P\pi r^2 \left\{ \log.(1+\cos.^2 i) - \cos.^2 i \right\}_0^{\frac{\pi}{2}} =$$

$$= \tfrac{1}{2} P\pi r^2 (1 - \log. 2) = .6136$$

$$P \times \tfrac{1}{4}\pi r^2 = .4821 \, Pr^2 \quad . \quad . \quad (7)$$

For the whole wind pressure

$$4X = .6136 \, P \times \pi r^2 = 1.9284 \, Pr^2 \quad . \quad . \quad (8)$$

Hence the X component of the pressure is equivalent to a pressure of .6136 P on each unit of the meridian plane YAZ.

The horizontal shearing strain between the dome and its supports, which is equal to the transverse shearing strain of the supports, is evidently $= 4X \cos. a$.

The moment of the wind pressure about the foot of the supports is equal to $4Xh \cos. a$, h being the height of the supports.

TO FIND THE COMPONENT Z.

The pressure on the band being constant the Z component of that pressure will be equal to the pressure multiplied by the length of the average ordinate (z say), divided by r. This ordinate is equal to the distance of the center of gravity of the quadrant cde from co.

Now, $z = \frac{2}{\pi} Oe = \frac{2}{\pi} r \sin. i$, $\frac{z}{r} = \frac{2}{\pi} \sin. i$.

Hence, by (3), $Z = 2Pr^2 \int \frac{\cos.^2 i \sin.^2 i \, di}{1+\cos.^2 i}$

$$= 2 \, Pr^2 \int \frac{\sin.^2 i - \sin.^4 i}{1+\cos.^2 i} di. \quad (9)$$

$$= 2 \, Pr^2 \int \left(\sin.^2 i + 1 - \frac{2}{2-\sin.^2 i} \right) di, \text{ by partial fractions.}$$

$$= 2Pr^2 \left\{ \int (\sin.^2 i + 1) \, di - \int \frac{\frac{1}{2}\sqrt{2} di \, i}{\sqrt{2}+\sin. i} - \int \frac{\frac{1}{2}\sqrt{2} di}{\sqrt{2}-\sin. i} \right\} \text{ similarly.} \quad (10)$$

Now, $\int \frac{di}{\sqrt{2}+\sin. i} = \frac{2}{(2-1)^{\frac{1}{2}}} \tan.^{-1} \left\{ \frac{\sqrt{2}}{(2-1)^{\frac{1}{2}}} \left(\tan. \frac{i}{2} + \frac{1}{\sqrt{2}} \right) \right\} = 2 \tan.^{-1} \left\{ \sqrt{2} \left(\tan. \frac{i}{2} + \frac{1}{\sqrt{2}} \right) \right\}$

Similarly, $\int \frac{di}{\sqrt{2}-\sin. i} = 2 \tan.^{-1} \left\{ \sqrt{2} \left(\tan. \frac{i}{2} - \frac{1}{\sqrt{2}} \right) \right\}$

$$\therefore Z = 2Pr^2 \left[\frac{i - \sin. i \cos. i}{2} + i - \sqrt{2} \tan.^{-1} \left\{ \sqrt{2} \left(\tan. \frac{i}{2} + \frac{1}{\sqrt{2}} \right) \right\} - \right.$$

$$\left. - \sqrt{2} \tan.^{-1} \left\{ \sqrt{2} \left(\tan. \frac{i}{2} - \frac{1}{\sqrt{2}} \right) \right\} \right]_0^{\frac{\pi}{2}}$$

$$= 2 \, Pr^2 \left\{ \frac{3\pi}{4} - \sqrt{2} \tan.^{-1} \left(\sqrt{2}+1 \right) - \right.$$

$$\left. - \sqrt{2} \tan.^{-1} \left(\sqrt{2}-1 \right) \right\} = 2Pr^2 \left(\frac{3\pi}{4} - 2\sqrt{2} \tan.^{-1} 1 \right)$$

$$= 2 \, Pr^2 \left(\frac{3\pi}{4} - \sqrt{2} . \frac{\pi}{2} \right) = \tfrac{1}{2} P\pi r^2 (3 - 2\sqrt{2})$$

$$= .3432 \, P \times \tfrac{1}{4}\pi r^2 = .2695 \, Pr^2. \quad (11)$$

The Z components of the pressure, above and below the plane XAY, are each equal to $2Z = .5391 \, Pr^2$. . . . (12)

Similarly the Y components on either side of the plane XAZ are each equal to $2Y = .5391 \, Pr^2$. . . . . (12)

The wind tends, therefore, to compress and distort the dome laterally and vertically, but not in the direction of the wind.

For a hemispherical dome, with the wind horizontal, we have from equations (5), (7) and (11),

$$2N = .4292 \, P\pi r^2 \quad . \quad . \quad (13)$$

$$2X = .6136 \, P \tfrac{1}{2}\pi r^2 \quad . \quad . \quad (14)$$

$$2Z = .3432 \, P \tfrac{1}{2}\pi r^2 \quad . \quad . \quad (15)$$

$$Y = .3432 \, P \tfrac{1}{4}\pi r^2 \quad . \quad . \quad (16)$$

In this case the additional *load* due to the wind pressure is, $.3432 \, P \tfrac{1}{2}\pi r^2$, given by (15).

TO FIND THE POINT OF APPLICATION OF X.

The moment of dX about A is equal to dX multiplied by the distance of the center of gravity of cde from cO.

$$\therefore dm = dX . \frac{2}{\pi} cO = dX \frac{2}{\pi} r \sin. i = \frac{2}{\pi} r \cos. i \sin. i \, dN.$$

Hence, by (3) we have, $M=2Pr^3$

$$\int \frac{\sin.^2 i \cos.^2 i\, di}{1+\cos.^2 i} \quad . \quad (17)$$

Now $\int \frac{\sin.^2 i \cos.^2 i\, di}{1+\cos.^2 i} = \int \cos. i \left(\frac{2\cos.^2 i}{1+\cos.^2 i} - \cos.^2 i\right) di =$

$$= \int \left(2\cos. i - \cos.^2 i - \frac{2\cos. i}{1+\cos.^2 i}\right) di$$

$$= \int (2\cos. i - \cos.^2 i)\, di - 2 \int \frac{d \sin. i}{2 - \sin.^2 i} \quad . \quad . \quad . \quad (18)$$

$$= \left\{ 2\sin. i - \frac{\sin. i \cos.^2 i}{3} - \frac{2}{3}\sin. i + \frac{1}{\sqrt{2}} [\log. (\sqrt{2} - \sin. i) - [\log. (\sqrt{2} + \sin. i)] \right\}_0^{\frac{\pi}{2}} \quad . \quad (19)$$

$$= \frac{4}{3} - \frac{1}{\sqrt{2}} \log. \frac{\sqrt{2}+1}{\sqrt{2}-1} = \frac{4}{3} - \frac{1}{\sqrt{2}}$$

$$\log. (3+2\sqrt{2}) = .0868$$

$$\therefore M = .1736 Pr^3 \quad . \quad . \quad . \quad . \quad (20)$$

$$\text{Now } \frac{M}{X} = \frac{.1736 Pr^3}{.4821 Pr^2} = .3601r = \overline{Z} \quad . \quad (21)$$

Since $.3601 = \sin.^{-1} 21°6'$, the point is 21°6′ from X on the arc XZ.

In a similar manner we have for Z, $dM' = dZr \cos. i$, which with (9) gives,

$$M' = 2Pr^3 \int \frac{\cos.^3 i \sin.^2 i\, di}{1+\cos.^2 i}$$ which is the same as (17).

Hence $M' = M = .1736\, Pr^3$ . . (22)

This follows, indeed, from elementary principles; for, since the pressure on the dome is normal to the surface, the total moment about A is equal to zero; or the moment of X is equal to the moment of Z.

$$\text{Now } \frac{M'}{Z} = \frac{.1736\, Pr^3}{.2695\, Pr^3} = .6440\, r \quad . \quad (23)$$

The point is therefore 40°5′27″ from Z on the arc ZX.

Dividing (11) by (7) gives,

$\frac{.2695}{.4821} = .55901 = \tan. 29°12'20''$, the angle made by the resultant wind pressure with the horizon.

The moments of X and Z about the center of the base of the dome being equal, it follows that the excess of the moment of X over that of Z about the foot of the supports, is equal to Xh, h being the height of the supports. This is the moment of the force that inclines the dome to the leeward.

Since the Y and Z components of the pressure on the part of the dome shown in the figures are equal, the resultant R of the normal pressure is,

$$R = (X^2 + 2Z^2)^{\frac{1}{2}} = 2Pr^2 [(.4821)^2 + 2 (.2695)^2]^{\frac{1}{2}} = .6145\, Pr^2 \quad . \quad . \quad (24)$$

Again, since the sum of the Y components on the whole dome is equal to zero, we have for the resultant of the whole normal pressure,

$$R = [(2X)^2 + (2Z)^2]^{\frac{1}{2}} = Pr^2 [(.9642)^2 + (.5391)^2]^{\frac{1}{2}} = 1.1047\, Pr^2 \quad . \quad . \quad (25)$$

The angle between the two partial resultants is given by,

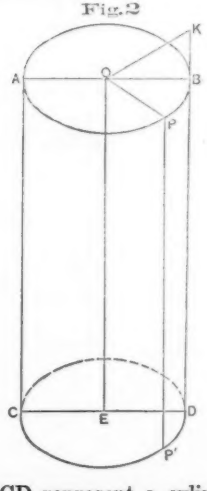
$$\cos. \theta = \frac{R_1^2 - 2R^2}{2R^2} = \frac{X^2}{X^2 \times 2Z^2} = .6154.$$

$\therefore \theta = 52°1'$. The partial resultants therefore, make an angle of 26°30″ with the plane XZ.

The pressure on the plane XZ is, therefore, R sin. 26°30″ $= .6145\ PR^2 \times .4385 = .2695\, PR^2$, which is the pressure in the direction YA . . . . . (26)

This agrees with (11).

Fig. 2



Let ABCD represent a cylinder with

the axis vertical; r=radius, l=length. Let K O be the direction of the wind, and P any point on the surface.

Let KOB=a, BOP=i and KOP=θ.

Now cos. KOP=cos. KOB cos. BOP; or cos θ=cos. a cos. i.

Hence,

$$\frac{1}{1+\frac{1}{2}\tan.^2\theta}=\frac{2\cos.^2\theta}{2\cos.^2\theta+\sin.^2\theta}$$

$$=2\frac{\cos.^2a\cos.^2i}{1+\cos.^2a\cos.^2i}$$

$$=2\left(1-\frac{1}{1+\cos.^2a\cos.^2i}\right)$$

$$=2\left(1-\frac{1}{\sin.^2i+(1+\cos.^2a)\cos^2i}\right)$$

The area of an elementary strip adjacent to the element PP′ is equal to $rldi$.

Hence the normal pressure

$$=2N=2rPl$$

$$\int\left(di-\frac{di}{\sin^2i+(1+\cos.^2a)\cos^2i}\right)_0^{\frac{\pi}{2}}\times 2$$

$$=4rPl\left\{i-\frac{1}{(1+\cos.^2a)^{\frac{1}{2}}}\tan.^{-1}\right.$$

$$\left.\frac{1}{(1+\cos.^2a)^{\frac{1}{2}}}\tan.\ i\right\}_0^{\frac{\pi}{2}}$$

$$=4rPl\left(\frac{\pi}{2}-\frac{1}{(1+\cos.^2a)^{\frac{1}{2}}}\cdot\frac{\pi}{2}\right)$$

$$=\pi rPl\left(2-\frac{2}{(1+\cos.^2a)^{\frac{1}{2}}}\right). \quad (27)$$

If $a=o$, $2N=\pi rPl\,(2-\sqrt{2})=$

$$=.5858\,P\pi rl \quad . \quad . \quad (28)$$

The average normal pressure is, therefore, .5858 on each unit.

The pressure in the direction BO is, evidently

$$2H=2Prl\int\left(\cos.i\,di-\right.$$

$$\left.-\frac{\cos.i\,di}{\sin^2i+(1+\cos.^2a)\cos^2i}\right)_0^{\frac{\pi}{2}}\times 2$$

$$=4Prl\int\left(d\sin.i-\frac{1}{\cos.^2a}\cdot\right.$$

$$\left.\frac{d\sin.i}{\frac{1+\cos.^2a}{\cos.^2a}-\sin.^2i}\right)$$

$$=4Prl\left(\sin.i-\frac{1}{2\cos.a\,(1+\cos.^2a)^{\frac{1}{2}}}\right.$$

$$\left.\log.\frac{(1+\cos.^2a)^{\frac{1}{2}}+\cos.a\sin.i}{(1+\cos.^2a)^{\frac{1}{2}}-\cos.a\sin.i}\right)_0^{\frac{\pi}{2}}$$

$$=4Prl\left(1-\frac{1}{2\cos.a(1+\cos.^2a)^{\frac{1}{2}}}\log.\right.$$

$$\left.\frac{(1+\cos.^2a)^{\frac{1}{2}}+\cos.a}{(1+\cos.^2a)^{\frac{1}{2}}-\cos.a}\right) \quad . \quad . \quad (29)$$

If $a=o$, $2H=4\,Prl$

$$\left(1-\frac{1}{2\sqrt{2}}\log.\frac{\sqrt{2}+1}{\sqrt{2}-1}\right)=.7536P\times 2rl \quad (30)$$

This is equivalent to .7536 P on each unit of the meridian plane.

The lateral pressure, normal to the plane ABCD, is evidently,

$$Y=2\,Prl\int\left(\sin.i\,di-\frac{\sin.\,di}{1+\sin^2a\cos.^2i}\right.$$

$$=2\,Prl\int\left(\sin.i\,di-\frac{1}{\cos.^2a}\cdot\right.$$

$$\left.\frac{\sin.i\,di}{\frac{1}{\cos.^2a}+\cos.^2i}\right)$$

$$=2\,Prl\left\{-\cos.i-\frac{1}{\cos.\,a}\right.$$

$$\left.\tan.^{-1}\cos.a\cos.i\right\}_0^{\frac{\pi}{2}} \quad . \quad . \quad (31)$$

$$=2\,Prl\left(1-\frac{1}{\cos.\,a}\tan.^{-1}\cos.a\right) \quad . \quad (32)$$

If $a=o$, $Y=Prl\left(2-\frac{\pi}{2}\right)=.4292\,Prl.$ (33)

This is equivalent to a pressure of .4292 P on each unit of the plane OBD.

The shearing strain is given by (30), and is, H=1.5072 Prl.

The moment of H about the foot of the supports is H $(\frac{1}{2}r+h)$, h being the height of the supports.

If the axis of the cylinder is horizontal, N and H are given as before, and Z, which is the same as Y in the preceding case, is given, of course, by equations (32) and (33.)

Let β= the angle between the direction of the wind and the horizon. This is equal to the angle between H and the horizon, or Z and the vertical plane through the axis of the cylinder.

The moment of H about the foot of the supports is therefore, H $(\frac{1}{2}r+h)$ cos. β.

Let us consider a right cone standing upon its base.

Let $2r$=the vertical angle of the cone.

Let a=the angle between the direction of the wind and the normal to the axis, the angle being considered positive downward.

$a+v$=the angle between the direction of the wind and the normal to the element of the cone on the windward side.

Substituting this for a, and the convex surface of the cone for that of the cylinder in eqs. (27), (29) and (32), we have,

$$2N=\tfrac{1}{2}P\pi rl\left(2-\frac{2}{(1+\cos.^2(a+v))^{\frac{1}{2}}}\right) \quad (34)$$

$$2H=2Prl\left(1-\frac{1}{2\cos.(a+v)[1+\cos.^2(a+v)]^{\frac{1}{2}}}\right.$$

$$\left.\log.\frac{(1+\cos.^2(a+v))^{\frac{1}{2}}+\cos.(a+v)}{(1+\cos.^2(a+v))^{\frac{1}{2}}-\cos.(a+v)}\right). \quad (35)$$

$$Y=Prl\left(1-\frac{1}{\cos.(a+v)}\tan.^{-1}\cos.(a+v)\right). \quad (36)$$

If the wind is horizontal, $a=o$, and the above equations become,

$$2N=\tfrac{1}{2}Prl\left(2-\frac{2}{(1+\cos.^2v)^{\frac{1}{2}}}\right) \quad . \quad . \quad . \quad (37)$$

$$2H=2Prl\left(1-\frac{1}{\cos.v\,(1+\cos.^2v)^{\frac{1}{2}}}\log.\right.$$

$$\left.\frac{(1+\cos.^2v)^{\frac{1}{2}}+\cos.r}{(1+\cos.^2v)^{\frac{1}{2}}-\cos.r}\right) \quad . \quad (38)$$

$$Y=\left(1-\frac{1}{\cos.v}\tan.^{-1}\cos.v\right) \quad . \quad . \quad . \quad (39)$$

If $a=-v$, the wind is normal to the element of the cone on the windward side, and equations (34), (35) and (36), become,

$$2N=\tfrac{1}{2}\pi rPl\,(2-\sqrt{2}) \quad . \quad . \quad . \quad . \quad (40)$$

$$2H=2Prl\left(1-\frac{1}{2\sqrt{2}}\log.\frac{\sqrt{2}+1}{\sqrt{2}-1}\right). \quad (41)$$

$$Y=\tfrac{1}{2}Prl\left(2-\frac{\pi}{2}\right) \quad . \quad . \quad . \quad . \quad . \quad (42)$$

These equations are just one half of equations (28), (30), and (33), as they ought to be, since the surface of the cone is one-half that of the cylinder.

The moment of H about the foot of the supports is evidently

$$M=H\left(\tfrac{1}{3}l+h\right)\cos.a \quad . \quad . \quad . \quad (43)$$

Which becomes, $M'=H\left(\tfrac{1}{3}l+h\right)$ when the wind is horizontal . . . . . (44)

If the apex is downward, equations (34)....(39) apply by putting $-v$ for v. $-v$ however, gives the same results as $+v$ in equations (37), (38), and (39), as it ought to do. The moment of H is the same as when the apex is uppermost, with $\frac{2}{3}l$ substituted for $\frac{1}{3}l$.

If the axis of the cone is horizontal, the same equations apply, as sufficiently explained with reference to the cylinder.

It is evident that the equations apply directly to a frustum of a cone, the convex surface of the frustum being substituted for the convex surface of the cone in the preceding equations.

II. Let us suppose the pressure upon a unit of area of surface to be, $P\cos.i=\frac{P}{\sec.i}$, i being the angle of incidence as before. Let us consider a hemispherical dome. Then the pressure on the band $cdec'e'$ in Fig. 1 is

$$dN=P\cos.i\,.\,\frac{\pi}{2}r^2\sin.i\,di=$$

$$=\tfrac{1}{2}P\pi r^2\cos.i\sin.i\,di \quad . \quad (45)$$

$$\therefore N=-\tfrac{1}{4}P\pi r^2\left\{\cos.^2i\right\}_o^{\frac{\pi}{2}}=$$

$$=\tfrac{1}{2}P\times\tfrac{1}{2}\pi r^2=.7854\,Pr^2 \quad . \quad (46)$$

On the whole dome, $2N=\frac{1}{2}P\times\pi r^2$. (47)

The average normal pressure is therefore equal to $\frac{1}{2}P$.

TO FIND X.

From (45), $dX=dN\cos.i=$

$$\tfrac{1}{2}P\pi r^2\cos.^2i\sin.i\,di$$

$$\therefore X=\tfrac{1}{2}P\pi r^2\int\cos.^2i\sin.i\,di=-\tfrac{1}{6}$$

$$P\pi r^2\left(\cos.^3i\right)_o^{\frac{\pi}{2}}=\tfrac{1}{6}P\pi r^2. \quad (48)$$

and $2X=\quad=\frac{2}{3}P\,\frac{1}{2}\pi r^2=\frac{1}{3}P\pi r^2$. (49)

Hence the X component of the pressure is equivalent to a pressure of $\frac{2}{3}P$ on each unit of the meridian plane YAZ.

TO FIND THE MOMENT AND THE POINT OF APPLICATION OF X.

The moment of dX about the point X is

$$dM=dX\,.\,\frac{2}{\pi}cO=dX\frac{2}{\pi}r\sin.i=$$

$$=Pr^3\cos.^2i\sin.^2i\,di. \quad (50)$$

$$\therefore M=Pr^3\int\left(\sin.^2i\,di-\sin.^4i\,di\right)=Pr^3$$

$$\left\{i-\frac{\sin.i\cos.i+2\sin.^3i\cos.i}{8}\right\}_o^{\frac{\pi}{2}}=$$

$$=\frac{\pi}{16}Pr^3. \quad (51)$$

Now $\frac{M}{X}=\frac{3}{8}r=\sin.^{-1}22°1'27''$ . . (52)

giving the point of application.

TO FIND THE VERTICAL COMPONENT Z.

From (45) and the equations preceding (9), the vertical component of the pressure on the band

$$=dZ=\frac{2}{\pi}\sin.i\times\tfrac{1}{2}P\pi r^2\cos.i\sin.i\,di=$$
$$=Pr^2\cos.i\sin.^3i\,di. \quad (53)$$

$$\therefore Z=Pr^2\int\sin.^3i\cos.i\,di=\tfrac{1}{3}Pr^2$$
$$\left\{\sin.^3 i\right\}_0^{\frac{\pi}{2}}=\tfrac{1}{3}Pr^2. \quad (54)$$

and $2Z=\frac{2}{3}Pr^2$. (55)

TO FIND THE MOMENT AND THE POINT OF APPLICATION OF Z.

Moment of $dZ=dM'=dZ\cos.i=Pr^3\cos.^3i\sin.^3i\,di$, which is the same as (50).

Hence, $M'=\frac{\pi}{16}Pr^3$.

and $\frac{M'}{Z}=\frac{3\pi}{16}r=.589r=\sin.^{-1}36°5'20''$.

Now the resultant, $R=(X^2+2Z^2)^{\frac{1}{2}}$

$=Pr^2[(.5236)^2+2\,(\frac{1}{3})^2]=Pr^2$
$(.27415696+.22222222)^{\frac{1}{2}}=.70454Pr^2$.

Also $R'=[(2X)^2+(2Z)^2]^{\frac{1}{2}}=$
$(1.09662784+.44444444)^{\frac{1}{2}}=1.2414\,Pr^2$.

The angle between the two partial resultants is given by,

$$\cos.\theta=\frac{X^2}{X^2+2Z^2}=\frac{.27415696}{.49637918}=.55231$$

$\therefore \theta=56°28'28''$ and $\frac{\theta}{2}=28°14'14''$ the angle the partial resultants make with the plane XZ.

The pressure on the plane XZ is, therefore, R sin.

$28°14'14''=.70454Pr^2\times.47312=\frac{1}{3}$
$Pr^2=Z=Y$, as before found. (56)

From (54) and (48) we have,

$\frac{Z}{X}=\frac{2}{\pi}=.63662=\tan.32°28'54''$ which is the angle the resultant makes with the plane XY.

As other results, in the light of the above, are easily found, it is not necessary to extend this part of the subject. It is probable, too, that the former results agree more nearly with experiments than the latter. The latter results are always greater than the former, as I will now show; and so probably err on the safe side.

We have, $\frac{\cos i}{1}=\frac{1}{\sec.i}=\frac{1}{(1+\tan.^2i)^{\frac{1}{2}}}$

and $\frac{1}{1+\frac{1}{2}\tan.^2i}=\frac{1}{(1+\tan.^2i+\frac{1}{4}\tan.^4i)^{\frac{1}{2}}}$.

We see that the above formulas meet, in general, every practical demand in reference to domes and their supports. They apply, also to the parts of bridges, including suspension cables, ropes and wires for the transmission of power, telegraph wires, etc. Also to water tanks, stand pipes, chimneys, towers, columns, etc.

The writer expects to deal still further with the general subject in a future article.

REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA—RECORD OF REGULAR MEETING, October 18th, 1884. President William Ludlow in the chair. Mr. C. Henry Roney showed a Portable Storage Battery for Mining and Exploring Purposes, with small incandescent lamps, illustrating his remarks with blackboard sketches. The battery shown was a modification of Planté's, devised by Dr. E. T. Starr, of Philadelphia, the electrodes consisting of V-shaped plates of sheet lead arranged over each other, the convexity downwards, with a slight interval between them, their ends attached to a lead frame by "burned" joints, the interstices between the plates being filled with finely divided metallic lead, exposing a large surface to oxidation and reduction when subjected to dynamic electric or voltaic energy, and, in turn, giving off a large percentage of the "stored" energy to incandescent lamps placed in the circuit. The battery shown measured $3\frac{1}{4}$ inches long, $2\frac{3}{4}$ inches high, and $\frac{3}{4}$ inch thick, and would maintain a small two-candle incandescent lamp at incandescence for about one hour. A battery sufficiently large to run an eight-candle lamp for ten or twelve hours would not be too large or heavy to carry conveniently for mine or other underground exploration.

Mr. W. L. Simpson exhibited and described the Thompson Indicator. He considers it handsome in design, and convenient and simple in arrangement. Cards can be taken with it at as high a pressure as 500 lbs. per square inch. All the moving parts are made very light and strong, which is a consideration of much importance in an indicator, especially when used on engines traveling at a high rate of piston speed. The coiled spring within the paper cylinder, for increasing or decreasing the tension of different speeds of engines, is so arranged that as little or much of it can be

taken up as may be desired. This is quite an improvement, as, formerly, a whole coil of the spring had to be taken up or none at all. By means of a jamb nut the horn handle screw can be set so as to regulate the pressure of the pencil on the paper, the back of the screw touching against a small post, and thus avoiding any strain tending to throw the parts out of line through too much pressure. To exchange springs is very easy, it only being necessary to unscrew the milled nut at the top of the steam cylinder, take out the piston with its arm and connections, disconnect the lever and piston by unscrewing the small knurled-headed screw which connects them, when the spring can be removed from the piston and the desired one substituted.

All springs made for this indicator are scaled, providing for 30 inches vacuum; and the capacity of any spring can be ascertained by a simple rule. To adapt the Thompson indicator to all pressures, springs can be made to any desired scale. The following are the most generally used: 8, 10, 12, 16, 20, 24, 30, 32, 40, 48, 50, 56, 60, 64, 80, 100. For pressures from 65 to 85 lbs. a 40 lb. spring is best adapted, for as 40 lbs. pressure on a 40 lb. spring will raise pencil one inch, 85 lbs. pressure on the same spring will raise pencil about two inches, which is the usual height of a diagram.

By means of the "detent motion," consisting of a pawl and spring stop, the paper cylinder can be stopped and the card taken off without unhooking the connecting rod. An arrangement of a swivel carrying a scored wheel allows the connecting cord to be run at any angle, so that it is possible to connect with any motion, of whatever kind, wherever it may be.

Mr. J. J. deKinder described the repairs to the 36-in. Belmont Submerged main, Philadelphia, recently made by him. The specially novel feature of this undertaking was a floating cofferdam, the bottom of which was built around the main, and the whole structure kept in exact balance, during freshets, etc., by two water-tight scows, suspended on its sides, into or out of which water was pumped to regulate the weight.

The rock lay so near the river bottom as to render a sheet-pile structure impossible.

W. Bugbee Smith introduced the subject of the Fire Protection of Mills. Mills must be properly built and furnished with adequate fire extinguishing apparatus. The best construction has been found to consist of heavy wooden posts and girders, solid plank floors and roof. The usual fire extinguishing apparatus consists of water buckets, hydrants and hose. In addition to this, some mills are furnished with perforated sprinkler pipes, running lengthwise through the mill, perforated with holes $\frac{1}{16}$ inch diameter and about nine inches apart. In case of a fire, by opening a valve outside of the building, water is let into the pipes and on the fire. The objection to this system is the fact that the water is not confined to the spot where the fire occurs, but is distributed over such a large area that much damage is done by it. It also requires human agency to make it effective.

To overcome these objections, automatic sprinklers, have been invented. These are valves, placed on a system of pipes near the ceiling and opened by the heat of the fire. They are kept closed by means of a fusible solder which melts at about 160° Fahr. The heat rising from a fire melts the solder joints of the sprinkler immediately over it, and thus the water is put just where it is needed.

There are two general classes of automatic sprinklers, the sealed, such as the Parmelee, Burritt, Rose and Bishop; and the sensitive, such as the Grinnell, Burritt, Brown & Hall, and the Kane. After describing the methods of piping a mill for each of the classes, samples of the above-mentioned sprinklers were exhibited and their peculiarities explained.

The automatic sprinklers have been in use about twelve years, and recent tests show that the fusible solder has not lost its strength and sensitiveness in that length of time, though exposed to pressure and water hammer.

The effectiveness of automatic sprinklers s fire extinguishers is shown by the fact, that out of 110 fires originating under them and of which the damage is known, for 67, or 60.9 per cent. of the whole number, no damage was claimed; for 12, or 10.9 per cent,, the damage was less than $250; for 8, or 7.2 per cent., between $250 and $500; for 11 or 9.9 per cent., between $500 or $1,000; for 12, or 10.9 per cent., between $1,000 and $20,000.

The Secretary exhibited, for Mr. S. L. Smedley, a photo-lithographic reproduction of a topographical map of Philadelphia, by John Hills, 1796, and pointed out some of the remarkable evidences of its great accuracy in detail.

Mr. Francis Lightfoot, of West Chester, introduced by the Secretary, explained a model of a Rail Joint in which no plates or loose pieces are required, the ends of the rail being lapped and bolted together through oblong slots.

NOVEMBER 1st, 1884. — President William Ludlow in the chair.

The Secretary presented, for Mr. A. W. Sheafer, Notes upon the Relative Cost of Haulage in the Anthracite Mines of Penna., by Mules and Locomotives. These embodied the results of investigations by Mr. Thomas H. Phillips, Supt. Kalmia Colliery. The results are as follows: Cost per ton per mile: by locomotive, $\frac{6}{10}$ cents, by mules $1\frac{87}{100}$ cents; saving, per ton per mile by locomotive, $1\frac{22}{100}$ cents. This includes operating expenses and depreciation, but does not include the additional number of cars and turnouts and repairs to roads, required for mule service.

The Secretary also exhibited for Mr. Sheafer, a set of Electrical Photographs of the Kohinoor Colliery Mine Workings. The exposures were from 20 to 30 minutes, and the results are excellent.

The Secretary exhibited the Bush Interlocking Rail Bolts, which interlock within the tie under the middle of the rail. They are specially intended, it is believed, to resist the lateral strain of the train upon curves.

Mr. Thomas M. Cleemann continued some previous remarks that he had made on the

Strength of Wrought Iron Columns, showing how some recent experiments by Mr. James Christie, at the Pencoyd Iron Works, gave values of the constants in Rankine's formula somewhat different from those generally used, and which would, therefore, be better to adopt, for calculating their strength, in structures of American iron.

In discussing the above, Mr. James Christie stated that the experiment referred to by Mr. Cleemann were subsequently supplemented by similar experiments on steel, and a basis established for the relations existing between steel and iron compression members for structures. In addition to the practical results obtained, the experiments were of peculiar interest, inasmuch as they add additional confirmation to the ordinary theory of flexure as propounded by Euler a century ago. Experiments on beams of iron and various grades of steel, show a practically uniform elasticity, however different the materials may be in ultimate tenacity. When the lengths of column are so great in proportion to cross dimensions that failure will occur almost entirely by bending, then the elasticity of the material is the sole measure of its resistance, and the common theory of flexure will apply. The experiments showed that when certain ratios of length to cross-section were reached, uniform resistance occurred between iron and steel, a fact, he believed, not heretofore known.

Capt. O. E. Michælis presented a blackboard description of what he was *allowed to see* at the recent exhibition of the "Keeley Motor" in Philadelphia.

ENGINEERING NOTES.

Construction of a Dry-Dock in Quicksand.—By — Zimmermann.—This dock was built at Hamburg for the Hamburg-American Steam Packet Company. The only available site was a narrow strip on the Bank of the Elbe, perpendicular to the river, partly below high water, and the soil so loose and porous that it would only stand at a slope of 1 in 4. The excavation was 390 feet long, 66 feet broad, and about 23 feet below low-water level as a maximum.

Want of space precluded the formation of a cofferdam, of several rows of sheet piles of varying heights, which would have been the safest arrangement, so it had to be constructed of a single line of sheet-piling, which not only had to support the entire pressure of the surrounding soil, but, owing to its unavoidable imperfect watertightness, allowed the water to percolate through the sides. The first step, therefore, was the setting up of four turbines for pumping out the water. The work demanded of them was the lifting of 15,275 cubic yards, a maximum height of 23 feet in three-and-a half hours; but they did it perfectly in half that time—that is, they lifted on an average 2.42 cubic yards per second.

In order to limit the depth to which the piles had to be driven as much as possible, the bottom of the dock was not made horizontal, but rounded, to correspond with the form of a vessel, so that to drive the piles down to 23 feet below low-water level was sufficient. The space enclosed by the piling was then dredged out. The concrete employed for the foundation was formed of 9 parts Luneburg lime, 7 trass, and 16 sand, mixed with twice that volume of broken stone, and was at first shot out for the entire thickness of the floor of the dock at once, by means of a wooden shoot or funnel attached to a traveling crane; but this arrangement did not answer well, for the shoot often splintered and broke, so an iron one had to be substituted. After the concrete had lain three months under water, the water was pumped out, and the concrete, though not perfectly set, was found sufficiently water-tight. Splinters of the wooden shoot were found in the concrete floor, and their removal caused strong springs or leaks, but these were successfully stopped by iron-cement.

On the concrete floor the side and front walls were built of brickwork, and carried up to summer flood-level, with a rebate or recess for a caisson, and all round the dock is a quay-wall reaching above highest flood-level.

After a time it was observed that the butting of the caisson against the walls loosened the mortar, and the recess was not watertight, but it was made completely so by a facing of planed cast iron with concrete backing.

The weight of the empty dock alone is not sufficient to resist the upward thrust of the water at very high tides; but when loaded with the weight of a ship there is, of course, an abundant margin; and when no ship is in dock it is arranged that so much water shall be admitted as will satisfy the conditions of safety. The work was carried out in 1868 to 1870, and cost £65,000.

IRON AND STEEL NOTES.

Constituents of Steel.—At the recent meeting of the Iron and Steel Institute, Mr. I. Lowthian Bell in the discussion of a paper on crucible steel, said, some importance seemed to be attached by Mr. Seebohm to the possibility of manganese existing in possibly two forms in steel. He had made no experiment with a view of ascertaining that, but it might interest Mr. Seebohm and Mr. Snelus, who also spoke on the subject, to know that not only carbon, but, as he believed, manganese was also occasionally separated in the way that carbon was, because upon one or two occasions, noticing a species of excrescence, as it were, on the face of pig-iron run from the blast furnace, he had this matter, which was silica in appearance, analyzed, aad found it contained not only a certain portion of carbon, but a considerable quantity of manganese, and also of silica—silica in such a state of mechanical texture as left no doubt at all on his mind that, in point of fact, the silicon had been extruded from the iron itself and oxidized as it met the air, and thus formed silica. He quite agreed with what fell from Mr. Seebohm as to the desirability of the chemist being appealed to, perhaps even more urgently than he had yet been appealed to, with regard to explaining certain differences in the quality of steel, and, indeed of iron, generally. If the chemist up to that time had not succeed-

ed in furnishing an explanation for all those differences, gentlemen must remember that the science of chemistry as applied to iron, certainly in this country, was somewhat new, and that the quantity of matter necessarily very seriously affecting the quality of the steel was so minute that they could scarcely be surprised if the researches of chemists had not yet mastered with sufficient exactness all the details required for ascertaining and detecting the presence of matter in such small quantities as were required for effecting the object he had just referred to. He might state that only recently, at the Monkbridge Iron-works, they were making iron, and they found it to be very red short. Mr. Kitson sent a specimen to him in order that he might ascertain if possible, the cause of this. Believing it possible that occluded oxygen might be at the root of the evil, he had some experiments tried upon the old lines, and found nothing to induce him to believe that oxygen was at the root of the evil; but happening to fall upon a recently discovered method of estimating the quantity of oxygen in iron, he had that tried, and then he found that in the red short iron there was fully double the quantity of oxygen in some form or another than there was in the specimens that were not red short. He merely mentioned this circumstance to show that they must not be impatient, but must work diligently and carefully in order to make themselves properly acquainted with all the circumstances and conditions which affected the quality of the material in the manufacture of which they had so great an interest.

RAILWAY NOTES.

FRENCH RAILWAY ROLLING-STOCK.—There are altogether, on French railways, 6,893 locomotives, of which 2,826 are passenger, and 4,067 goods engines. There are also 15,432 carriages, of which 3,208 are first-class, 5,315 second-class, and 6,909 third-class, together with 182,089 wagons. As regards the principal companies, the following are the figures: Northern, 1,138 locomotives, 2,021 carriages, and 33,971 wagons; Eastern, 922 locomotives, 2,359 carriages, and 22,401 wagons; Western, 1,045 locomotives, 2,881 carriages, and 17,465 wagons; Orleans, 970 locomotives, 2,100 carriages, and 40,433 wagons; Paris-Lyons-Mediterranean 1,960 locomotives, 3,489 carriages, and 62,200 wagons.

ORDNANCE AND NAVAL.

THE HEAVY GUNS OF 1884.—This formed the subject of a lecture delivered by Colonel E. Maitland, R.A., superintendent of the Gun Factory, Woolwich, before the United Service Institution, on June 20. The walls of the theater were covered with diagrams of the latest piece of ordnance and sections of breeches, whilst the floor was occupied by a steel cannon and the breech of one of the new pattern interrupted screw breechloading guns Colonel Maitland said this was the time for laying before the public as clear an exposition as possible of the subject, which was one of national importance, setting forth the causes which had led to the necessity for the re-armament of our naval and military forces, the progress now made in that re-armament, and the comparative efficiency of the heavy guns of 1884 in England and in the other chief countries of the world. The chief causes which had led to the necessity for the changes in our armament were—first, the improvement in powder; secondly, the improvement in mechanical appliances; and, thirdly, the improvement in production of large masses of steel. These considerations had affected the great continnetal powers, for they also were re-arming extensively, though the changes being made on the Continent were more gradual and less radical than our own. In the latter part of the seventies (the period between 1869 and 1880) England certainly fell behind in the artillery race, but not to the extent supposed by many who had not studied the subject. As a matter of fact the old short breechloaders of the Continent were just as obsolete now as the old short muzzle-loaders of England, and up to 1875 or 1876 the British artillery was as good as anybody else's. Then came a period of stagnation, and we fell to leeward. This country, however, had not been caught napping by an important war, but in waiting had got the best of the artillery contest. Colonel Maitland then, for the information of non-artillerists, dealt with some of the technicalities of the gunner's craft, and explained the improvements which had occurred in the making of gunpowder, one improvement being an increased energy given to the projectile by the slowing of the powder, so that it should burn while the projectile was traversing the bore and increase in burning until the projectile was about to leave the muzzle. He discussed the important question of powder at length, and showed that the improvements in it had rendered breechloading in the guns to be an absolute necessity, as the guns had now to be made so long that loading from the muzzle became practically impossible on service, and the projectile had to be held fast until a pressure of from 1 ton to 2 tons per square inch was set up in the chamber, which could only be done in breech-loading guns. He spoke warmly of the promptitude with which Colonel Brackenbury, of the Woolwich Gunpowder Factory, had grappled with the difficulties of giving a suitable powder for improved English guns. Having referred to the cocoa powder of the Germans —a secret—Colonel Maitland dealt with the subject of breechloading and remarked that a satisfactory closing of the breech was not accomplished by any nation until after the Franco-German war of 1870-71, after which period Krupp entirely remodeled his breech fittings, and the French adopted an entirely new method of obturation, invented by Dr. Bange, of the French artillery. Colonel Maitland then stated that we had in hand guns of an efficient character up to 110 tons. He next spoke upon the Krupp system, the French marine system, the French land service system, and, lastly, upon the improvements which had been adopted in some of our own guns, the trials of these systems, and the avoidance of some defects discovered in working. He presented a section of the Elswick gun of 110 tons, being manufac-

tured for the government by Sir W. Armstrong, Mitchell & Co. This gun, he said, was entirely of steel, and had three layers of hoops over the breech-piece. In this gun there would be several important improvements upon the 100-ton gun of the Italian government. As to the adoption of steel for breechloaders, he justified the adoption of the metal, now thoroughly tested by German experience, and declared that England, in coming last, had really got the best forged steel construction known in guns. He considered that England had obtained all the advantages of France and Germany combined, and, moreover, not being hampered by the necessity of utilizing old material, we had been able to devote all our energies to new guns of the best quality, instead of altering old guns of inferior type. We had, moreover, greatly extended the ballistics of our guns, and had conferred on them unsurpassed powers in proportion to their weight. In conclusion, he said that now the time had arrived for the country to face the question of re-armament seriously, to grant the money, and to push on the manufacture. After remarks made by several speakers upon different points in the lecture, the discussion was adjourned.

THE TORPEDO FITTINGS OF THE NAVY.—In the ships of war recently built and in those now in course of construction, the fitting of underwater torpedo gear has been abandoned, the experience derived from the practice of the *Inflexible* not having been altogether satisfactory. Ships designed for exclusively torpedo service, such as the *Vesuvius*, the *Polyphemus*, and the *Scout* (which is now being built on the Clyde) may continue to be provided with submerged projectiles, but even in these the torpedoes will probably be only discharged from the stem ports in consequence of the difficulty of expelling them from the broadside of a ship under way and the impossibility of firing them in a straight line. The best results have hitherto been obtained from the stem tubes, and from the great accession of speed which has been realized by the improved Whiteheads and the greater impulse which is communicated to them by the general adoption of the air-gun system, there is now no longer any danger to be apprehended from the projectile being overtaken and exploded by the ship from which it has been discharged. This desirable direct ahead fire has up to the present time been secured by two methods. In the Polyphemus, for instance, as in the similar case of the Italian turret-ship Duilio, the torpedo port is cut in the ram itself. This system has the obvious disadvantage of seriously weakening the spur and its attachments, and thus conducing to the crippling of the ship if not to its actual disablement. Provided a fair blow be delivered by the ram there will be no necessity to discharge a torpedo simultaneously with the blow to secure the complete destruction of an enemy; but should the blow, as happened in the case of the Defence and the Valiant, be deflected by a change of helm on the part of the enemy, the probability is that the spur of the Polyphemus would be so far disabled as not only to prevent her ramming a second time, but to prevent her using her torpedo armament. In the Inflexible, on the other hand, direct ahead fire is obtained by launching the torpedo over the stem by a sliding bar from above, a method which exposes the mechanism and the men handling it to the torpedo guns of an enemy. A new arrangement is now being introduced into the Camperdown, building at Portsmouth, and will also be embodied in the Scout and the Benbow. In addition to the four socket tubes on the broadside having a range of 70 degrees before and abaft the beam, or 20 degrees in a fore and aft line, the Camperdown is having a torpedo port worked in her brass stem on a level with the main deck and consequently high above the water line and her submerged prow. The gear and the men will consequently be well under cover. The torpedo, which is 16 feet long and 14 inches in diameter, is inserted in a steel cylinder of just sufficient dimensions to contain the projectile, and having a brass lining in which the grooves along which the T pieces of the torpedoes run are cut. The highly compressed air is admitted at the rear of the tube and in direct contact with the torpedo. In the old system the impulse was given by means of a piston, the blow from which when the engine was not in touch with it, was sometimes violent enough to injure the delicate mechanism of the torpedo. When everything is ready for firing, a touch of the firing key releases a brass ball magnetically held in position, the fall of which is made to rotate a lever, which in its turn releases the safety pin, and the torpedo is blown out of the ship. The only mishap which could possibly attend this method is the discharge of the torpedo before the port door had been opened, and the consequent explosion of the missile on board. This might be supposed to be an imaginary danger, but it has been practically provided against by an arrangement of levers. The port itself is elliptical, to allow for the fall of the torpedo in escaping from the ship; but the true nature of the parabola described by the torpedo in falling remains to be determined by careful observations. As the projectile leaves the tube a stud trips the trigger and sets the propelling engines in motion. —*London Times.*

BOOK NOTICES

PUBLICATIONS RECEIVED.

REPORT of the Commissioner of Education for the year 1882–83. Washington Government Printing Office.

Annual Report of the Chief of Engineers, United States Army. 1884.

Monthly Weather Review for September. Washington Signal Office.

Hydraulic Tables. Compiled by John W. Hill, M.E. Cincinnati: Robt. Clarke & Co.

House Drainage as Constructed by the Durham House Drainage Co. By Wm. Paul Gerhard. New York: D. Van Nostrand. Price 50 cents boards, $1.00 cloth.

PROCEEDINGS OF THE UNITED STATES NAVAL INSTITUTE. Vol. X. THE ESTABLISHMENT OF STEEL GUN FACTORIES IN THE UNITED STATES. By Lieut. W. H. JAQUES, U. S. N. Annapolis, Md.: Naval institute.

The subject of this volume is of deep interest to many. The author has aimed to show the necessity for the manufacture of steel guns in this country, and to provide a manual of reference for those who desire to know the details of the latest methods of manufacture.

The methods pursued in England, France, Germany, Russia and United States are described and fully illustrated by diagrams.

An enumeration of the machines and tools for a plant for gun manufacture, and the "General Summary of the Gun Foundry Board" close the volume.

A TREATISE ON THE ADJUSTMENT OF OBSERVATIONS. By T. W. WRIGHT, B.A., late Assistant Engineer, United States Lake Survey. New York: D. Van Nostrand.

The method of obtaining the most reliable result from a series of observations or measurements, when such observations are multiplied for the sole purpose of securing accuracy, is a subject of profound study, which is alike profitable to the student of theory or to the practical worker. The author of the present treatise is fully in sympathy with both classes, and, moreover, exhibits the capabilities of an instructor.

The increasing demand for better accuracy in surveys of all kinds has been responded to by the production of better instruments. But given the best instruments and the best observers, the question of how to obtain the best results is still an open one. To the importance of this question, the attention of American students has not been heretofore sufficiently awakened. This treatise will be found to be a valuable stimulus to learners who aspire to the performance of good work in Surveying, Astronomy or Physics.

The introductory chapter fully sets forth the nature of the work to be accomplished, viz.: the elimination of the effects of errors in measurements of various kinds, and describes the sources and kinds of error whether inherent or accidental in either the observer or instrument, or external to both as in the atmospheric conditions; and summarizes the conditions as follows: "When all known corrections for instrument, for external conditions, and for peculiarities of the observer have been applied to a direct measure, have we obtained a correct value of the quantity measured? That we cannot say. If the observation is repeated a number of times with equal care different results will in general be obtained.

The reason why the different measures may be expected to disagree with one another has been indicated in the preceding changes. There may have been no change in the conditions of sufficient importance to have attracted the observer's attention when making the observations, but he may have handled the instrument differently, turned certain screws with a more or less delicate touch, and the external conditions may have been different. What the real disturbing causes were he has no means of knowing fully. If he had he would correct for them, and so bring the measures into accordance. Infinite knowledge alone could do this. With our limited powers we must expect a residuum of error in our best executed measures, and, instead of certainty in our results, look only for probability.

The discrepancies from the true value due to these unexplained disturbing causes we call *errors*. These errors are *accidental*, being wholly beyond all our efforts to control. As soon as they are known to be *constant*, or we learn the law of their operation, they cease to be classed as errors.

A very troublesome source of discrepancies in measured values arises from *mistakes* made by the observer in reading his instrument or recording his readings. Mistakes from imperfect hearing, from transposition of figures, and from writing one figure when another is intended, from mistaking one figure on a graduated scale for another, as 7 for 9, 3 for 8, etc., are not uncommon. These also must be classed as accidental errors, theoretically at least. Having, therefore, taken all possible precautions in making the observation, and applied all known corrections to the observed values, the resulting values which we shall in future refer to as *observed values* may be assumed to contain all accidental errors. We are then brought face to face with the question, "How shall the value of the quantity sought be found from these different observed values?"

This is followed by a brief synopsis of the mathematical principles involved in the treatise: Probabilities, Definite Integrals, Taylor's Theorem, Interpolation, and Periodic Series. This synopsis is only just full enough to inform the reader in advance of the stock of mathematical knowledge requisite for the mastery of the treatise. It is only intended to remind, not to instruct him.

The second chapter deals with the Law of Error, and we believe will be found full of interest to the mathematical student. The author shows how the accepted methods were evolved, and presents the earlier processes in historical order.

The chief topics of this chapter are: The Arithmetical Mean; Law of Error of a Single Observed Quantity; Law of Error of a Linear Function of Independently Observed Quantities; Comparison of the Accuracy of Different Series of Observations; The Probability Curve; The Law of Error Applied to an Actual Series of Observations; Classification of Observations.

There is an important appendix to this chapter at the end of the volume.

Chapter III. treats of the adjustment of Direct Observations of One Unknown Quantity. The principal topics are: Observed Values of Equal Quality; Observed Values of Different Quality; Observed Values, Multiples of Unknown; Precision of a Linear Function of Independently Observed Values.

This chapter contains a large number of examples of "Mean Square" and "Probable Error." Also two appended notes relating respectively to Weighting of Observations and Rejection of Observations. In this latter note we find the following remark regarding a *criterion* for rejection, with which we believe all practical workers will find themselves in accord.

"It may be stated, as a general rule, that criterions are apt to be most highly esteemed by those who look at the observations from a purely mathematical rather than from a practical observer's point of view. The latter is, without doubt, the true standpoint. Every observer will consciously or unconsciously construct a criterion suited to the sort of work he is engaged in. This criterion will not necessarily be founded altogether on mathematical formulas. Indeed, most likely it will not be. Nor does it follow that the criterion adopted in any special series is of universal application or will receive universal assent. In the process of weighting, the observer will not assign weights always as the inverse squares of the "mean square error." It is often better to assign them arbitrarily from a feeling founded on a general grasp of all the circumstances connected with the making of the observations. In like manner, and in this same feeling, he will found his criterion for rejection. There is no uniform rule for weighting; neither is there one for rejection."

Chapter IV., on Adjustment of Indirect Observations, deals at much length with Determination of Most Probable Values. This is followed by: Precision of the Most Probable (Adjusted) Values; Precision of any Function of the Adjusted Values; Average Value of the Ratio of the Weight of an Observed Value to its Adjusted Value and Artifices of Elimination.

The theoretical part of the treatise is completed in Chapter V., which presents the consideration of the adjustment of a series of observations which are not entirely independent of each other. This is termed the Adjustment of Conditional Observations. A general statement of the character of the problem is followed by: The Direct Solution (Independent Unknowns); The Indirect Solution (Method of Correlates); Solution in Two Groups; Solution by Successive Approximations.

Examples are interspersed as in the preceding chapters.

The remaining portion, nearly half of the volume, exhibits applications of the principles elucidated in the foregoing chapters. The examples are mostly from American practice. They are divided as follows:

Chapter VI., Triangulation; Chapter VII., Base Line Measurements; Chapter VIII., Leveling; Chapter IX., Graduation of Line Measures, and Calibration of Thermometers; Chapter X., Empirical Formulas and Interpolation.

The work throughout exhibits signs of careful preparation, and we believe it will be regarded as a very valuable contribution to English scientific literature.

FORESTRY IN THE MINING DISTRICTS OF THE URAL MOUNTAINS. Compiled by JOHN CROUMBIE BROWN, LL. D. London: Simpkin, Marshall & Co.

This work, like the later ones of this industrious writer, is carefully compiled from reliable sources and is exceedingly compact.

The chapters present in order the following ubjects: Journey from St. Petersburg; Forest Exploitation in Ufa; Mishaps in Traveling; Russia and her People; The Ural Mountains; Metallurgy; Forests; Depressed Condition of Mining and Manufacturing; Forest Exploitation; Abuses in Exploitation of Forests; Occasion of Diminished Supply of Wood; Glimpses of Life; Laboring Population: The Conquest of Siberia.

A COURSE OF QUALITATIVE CHEMICAL ANALYSIS. By W. GEO. VALENTIN, F.C.S. Revised by W. R. HODGKINSON, Ph. D. Sixth Edition. Philadelphia: P. Blakiston, Son & Co.

The merits of Valentin's work are well known to workers in the laboratory. The notation is that of Frankland, while the methods of separation are largely original with the author and editors.

Students using the text as a guide to practical analysis, find the full directions for their work especially convenient.

The examination questions which are appended to each section, serve to direct the learner's attention to the more salient points. Some advantage to the student is also afforded by occasionally presenting the graphic symbol of a compound.

The work is particularly good in the matter of detection of the acids and in the reactions of the rare metals. The latter portion representing the later additions to the book.

THE STEAM ENGINE INDICATOR AND ITS USE. By WILLIAM BARNET LEVAN. New York: D. Van Nostrand.

The literature of the indicator is by no means scanty. There are not wanting essays upon this instrument which treat, more or less lucidly, upon its peculiarities, but many of them presuppose a certain familiarity with the indicator upon the part of the student, and plunge, *in medias res*, on the first pages. In regard to the indicator itself, a revival is in progress. A class whom it is very essential to educate have taken it up and are availing themselves of its offices. They know nothing of it beyond the fact of its existence and are exceedingly anxious to learn. It is manifest that, for such readers, the treatment should be severely simple and rudimentary. It is difficult for many writers, who essay the task of teaching beginners, to comprehend this, this after brief allusions to the object of the indicator they proceed, without loss of time, to thermal units and adiabatic curves. Moreover, many works on the indicator are useless to students by reason of the mathematical processes of elucidation employed. It is natural that an expert should couch his expressions in the shortest and most concise terms, but this cuts off a great many from availing themselves of the instruction given, for reasons sufficiently obvious to require no pointing out.

In *The Steam Indicator and Its Use*, by Wm. Barnet LeVan, provision has been made for the class mentioned before. They are specially addressed, in point of fact, in simple language and by plain diagrams. Starting with a detailed description of the indicator, the author proceeds by easy stages to simple diagrams, explaining in terse language how they are produced, the best methods of taking them, and

lastly, how to compute the areas enclosed. All this is accompanied by the necessary diagrams, so that any person who is fit to be about an engine at all can use the indicator practically.

Another point in favor of the work for those for whom it is compiled, is its low price. It is issued from the press of D. Van Nostrand & Co., in their admirable Science Series, a form which has rendered many valuable papers popular, and insured a reading for scientific treatises, taken from high class publications which the multitude would never see. This work on the Indicator is appreciated by those for whom it is written, and is selling well.

ANALYTIC MECHANICS. By E. A. BOWSER, Prof. of Mathematics and Engineering, Rutgers College, New Brunswick, N.J.; D. Van Nostrand, Publisher. 12mo. cloth. Price, $3.00.

An American text-book on Mechanics that would present its leading principles in a clear and simple way, and at the same time furnish a substantial preparation for its higher branches, has long been desired. The increasing applications of this branch of mathematics to the practical problems of engineering and architecture have made a knowledge of it necessary to success in these departments. No one can appreciate the advances made in the theories of Light, Heat and Electricity, who is not familiar with the methods of Dynamics.

The text-book of Prof. Bowser is admirably fitted for filling these conditions. He has succeeded in happily combining simplicity and clearness of treatment with a full exposition of some of the more difficult parts of the science.

The practical bearings of the principles are illustrated by their applications to the mechanical powers, while attention has been given to the requirements for a preliminary training in celestial and physical mechanics. The work involves the use of Analytic Geometry and the Calculus, and in itself is a valuable discipline in these branches of mathematics.

The chapters on "Moment of Inertia" and "Center of Gravity," furnish a fine illustration of the use and power of the calculus. The practical way in which the author passes from theoretical formulæ by means of numerous and wisely selected examples, to actual cases requiring arithmetical calculation, is a marked and valuable feature of the book, and makes an otherwise difficult subject, attainable and useful.

The chapter on Friction goes a great way toward divesting many of the problems of mechanics of their usually unreal character, in giving methods for dealing with the cases of bodies not perfectly smooth—cases of occurrence in things as we find them.

An entire chapter has been devoted to "Work and Energy," and these important terms are fully explained and their physical significance definitely pointed out.

Prof. Bowser has made a separate division of Kinematics—a science which bears the same relation to Dynamics that the science of Mechanism does to Mechanical Engineering.

The distinction between motion, regarded merely as change of place, and motion as produced by force has long been recognized, but seldom finds its way into our text-books. A large number of dynamical problems rest mainly on the relations between velocities, accelerations, &c., considered without reference to their causes, and there is a gain in clearness in making their treatment a separate part of the subject.

Under Kinetics the motions of bodies under the action of forces have been considered. The problems of central forces are taken up and illustrated, by showing that the Laws of Kepler are a necessary consequence of the law of gravitation.

A suggestive and instructive feature of the book is the many references to the standard works on the different branches of mechanics.

The treatment throughout is plain, direct and complete, and the arrangement is nicely adapted to purposes of instruction.

The book is of convenient size, neatly bound, and printed in clear type.

MISCELLANEOUS.

ON THE MEASUREMENT OF WIND-PRESSURE—INCOMPLETENESS OF BORDA'S FORMULA.—By DR. FINES.—Borda's formula for deducing pressure of wind from velocity is $F=C\times SV^2$, C being a constant coefficient for a certain plate, S the surface in square meters, V the velocity of the wind in meters per second, F the pressure of the wind in kilograms per square meter. C varies with size and shape of plate. Borda gives the following values:

C=0.092	kilo. for	plain plates of	0.011664 sq. me.
0.100	"	"	0.026244 "
0.104	"	"	0.059049 "
0.120	"	"	0.929000 "

The first three of the above values are given by Borda, the last by Rousse. Later, Navier found that in the case of movement in the atmosphere at 10° Centigrade, under the normal pressure C=0.1278. Thibault, however, found the value of C under the same conditions to be 0.1151. Dupré considered that Navier's formula, $R=0.1278\ SV^2$, is the right one to use.

The author states that Borda's formula gives rise to two sources of error, one owing to inaccuracy in the formula, the other to its application. Though the size and shape of the plate are known, the reciprocal reactions of the different currents of air one upon the other are not; neither are their absolute velocities, the mean velocity only is known.

The ordinary anemometer is incapable of recording the velocity of the wind at the time (of only a few seconds' duration) of the most violent gusts. M. Renard, however, made observations during the violent storm of November 16, 1880. He found that during an interval of twenty-five seconds the velocity increased from 38 to 51 meters per second, and then diminished in the following twenty seconds to 35.70 meters, so that during this short interval the pressure varied from 325 to 136 kilograms per square meter. These observations, however, do not give the absolute maximum intensity which can have lasted only a few seconds, and may have been much higher than that above stated, and it is the absolute maximum velocity which is required for an exact application of Borda's formula.—*Abstracts of Institution of Civil Engineers.*